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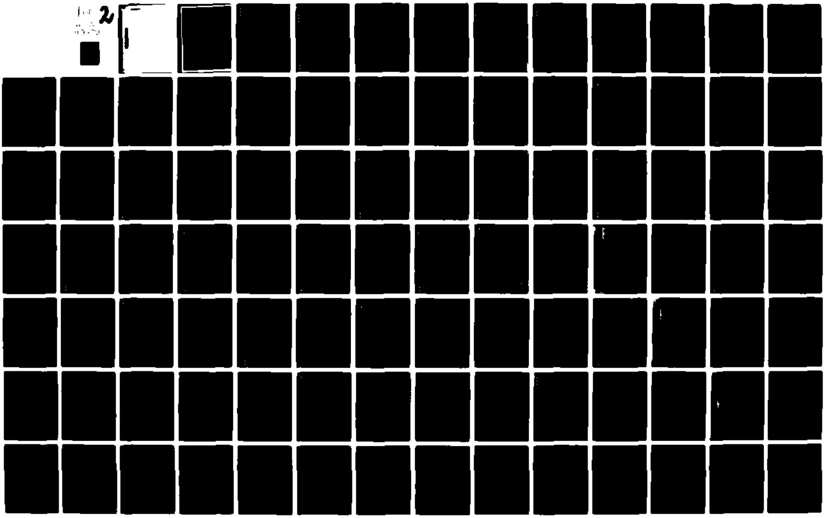

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This technical report has been reviewed and is approved for publication.

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This user's manual describes the vane and bleed optimization computer program (Customer Computer Deck CCD 1182). The program includes the capacity of handling four variable vanes and one bleed. The basic goal-seeking algorithm is the COPES/CONMIN approximate optimization method. The program includes a stage-by-stage compressor model that simulates an eleven stage, four variable vane compressor to demonstrate program capabilities. This document presents sample problems using the compressor simulation to help the user become familiar with the program deck.

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FOREWORD

United Technologies Corporation, Pratt & Whitney Aircraft Group, Government Products Division prepared this document for the Air Force Aero Propulsion Laboratory to meet the requirements of a User's Manual under Contract F33615-79-C-2013, Research on Software for Optimization of Vane and Bleed Settings in Multi-Stage Axial Compressors. This document complies with the Contract Statement of Work Item 5.0. The work described in this report was performed during the period 15 May 1979 to 15 May 1981. Efren Strain (1/Lt, USAF) is the Air Force Program Manager.

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SECTION I

INTRODUCTION

Gas turbine engines for jet aircraft must maintain high performance over a wide range of flight conditions. Thus, many of the components in these engines incorporate variable-geometry configurations and bleed systems to meet the requirements of changing environments. The fan and compressor normally contain a combination of variable vane rows and bleeds to accomplish this objective. Hence, optimization of variable vanes and bleeds or selection of the best vane and bleed schedule plays a very important role in compression system development. During initial development, most compressors are built with all vane rows variable, even though only a few rows may be variable in the final design configuration. Optimization objectives vary from configuration to configuration. However, typical examples of parameters requiring optimization include overall efficiency, surge margin, airflow, and pressure ratio.

Current optimization techniques generally consist of running a matrix of test points with various geometry settings, shutting down the test article, reviewing the interstage aerodynamics, selecting a new series of test points using engineering judgement, and further diagnostic testing. This process is very time-consuming and expensive and rarely achieves a true optimum.

Compressor test facilities are often linked to large computers for online data feedback. Experience in compressor development and system simulation indicates that utilizing a software package through a logical series of iterations could guide decisions of the test engineer and, thus, reduce the number of data points and test time required to achieve an optimum performance goal. Ultimately, a system could conceivably be used to control the search for optimum performance. This contract effort developed a computer program in FORTRAN IV language capable of guiding the optimization of vane and bleed settings in multi-stage axial compressors.

The technical approach to the development of software for optimization of vane and bleed settings in multi-stage axial compressors involved definition of optimization goals, development of the performance-seeking logic, creation of a computer program to complement the logic, and demonstration of the function of the software.

This user's manual describes the vane and bleed optimization computer program (Customer Computer Deck CCD 1182). The program includes the capacity of handling four variable vanes and one bleed. The basic goal-seeking algorithm is the COPES/CONMIN approximate optimization method described in Reference 1. The program includes a stage-by-stage compressor model that simulates an eleven-stage, four variable-vane compressor to demonstrate program capabilities. This document presents sample problems using the compressor simulation to help the user become familiar with the program deck.

ERRATA

Page	Line	Printed	Replace By
1	Item 10	Task 51	Task S1
3	3 from top	iterative	interactive
3	11 from bottom	COPES/COMIN	COPES/CONMIN
27	6 from top	CONMIM	CONMIN
29	8 from top	CONMIM	CONMIN
31	4 from bottom	nest	next

SECTION II

PROGRAM DESCRIPTION

Computer program CCD 1182-0.0, developed on an IBM 3033 computer, is a FORTRAN program capable of guiding the optimization of vane and bleed settings in multi-stage axial compressors. Operated through an iterative terminal, the computer program is designed to be used in a manual mode with real-time data reduction. Inputs include the optimization goal, vane and bleed setting limits (e.g., ±10 deg about the base vane setting), vane and bleed initial settings, performance constraints, and compressor rig measurements of overall performance. The main element of the computer program consists of the COPES/CONMIN approximate optimization algorithm that provides the test engineer with information required for the next vane or bleed setting. Flow charts showing program logic appear in Figures 1 and 2

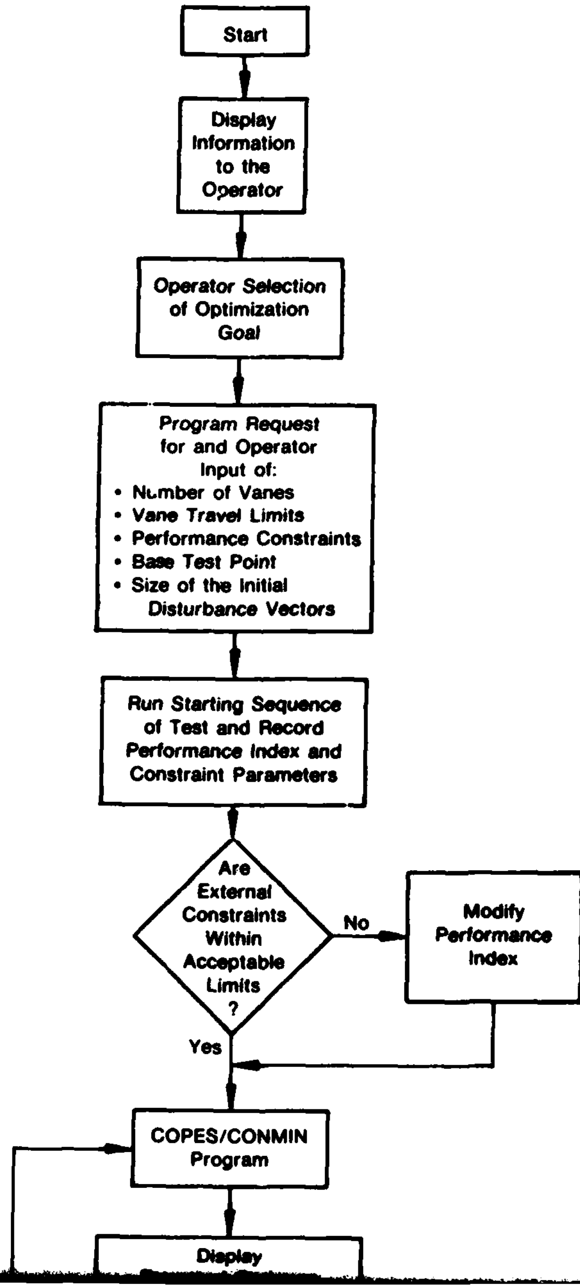
The vane optimization program primarily performs an information management task. The program supplies the computer terminal with several successive information displays based on stored data. The operator initially selects one of seventeen optimization goals summarized on the display screen. This display alone is sufficient to describe required operator actions and specific test goals.

The operator will then be prompted for the number of variable vanes and bleeds (N) to be optimized, upper and lower bounds for vane angle and bleed flow, and the size of the incremental vane and bleed variation used for the first N+1 test points. At this point, the program will tell the operator to run the base condition from which the optimization will begin. The operator is then prompted for the vane and bleed settings, and performance index *(and constraint values, if applicable).* The performance index and constraint values are defined based on the optimization goal selected. These may be efficiency, stall margin, corrected flow, or pressure ratio, all of which are available from the compressor test facility. The first basis vane angle and bleed perturbations are calculated and returned to the operator. The performance index and constraint values are input to the terminal. Additional basis vane angle and bleed perturbation cases are run until N+1 test points are run. The points run provide an initial model of the performance index function. After the performance index model is created, multiple optimization passes are made using this approximate design model. The approximated optimum vane and bleed settings (as determined by this pass) are sent to the operator. During the setting of new conditions, the operator monitors for external constraints, such as flutter or blade strain. If and when these limits are reached, the performance index may be modified to account for an aeromechanical constraint boundary. A convergence check and test for maximum iterations is made. The program control will return to COPES/CONMIN with the new data point. The COPES performance index model is updated and a new optimization iteration proceeds.

Following a convergence at the optimum, a description of the convergence criteria will be displayed and a complete documentation of the optimization path will be printed. The following paragraphs describe the program elements in detail.

INITIALIZATION

Data initialization occurs in two ways: through block data and through operator input. Block data is used to initialize the data which generally does not change from one test case to another. The optimization program will ask the operator for any further information required to complete the initialization for a given test case.


Start
Display Information to the Operator
Operator Selection of Optimization Goal
Program Request for and Operator Input of:
• Number of Vanes
• Vane Travel Limits
• Performance Constraints
• Base Test Point
• Size of the Initial Disturbance Vectors
Run Starting Sequence of Test and Record Performance Index and Constraint Parameters
Are External Constraints Within Acceptable Limits ?
No
Modify Performance Index
Yes
COPES/CONMIN Program
Display

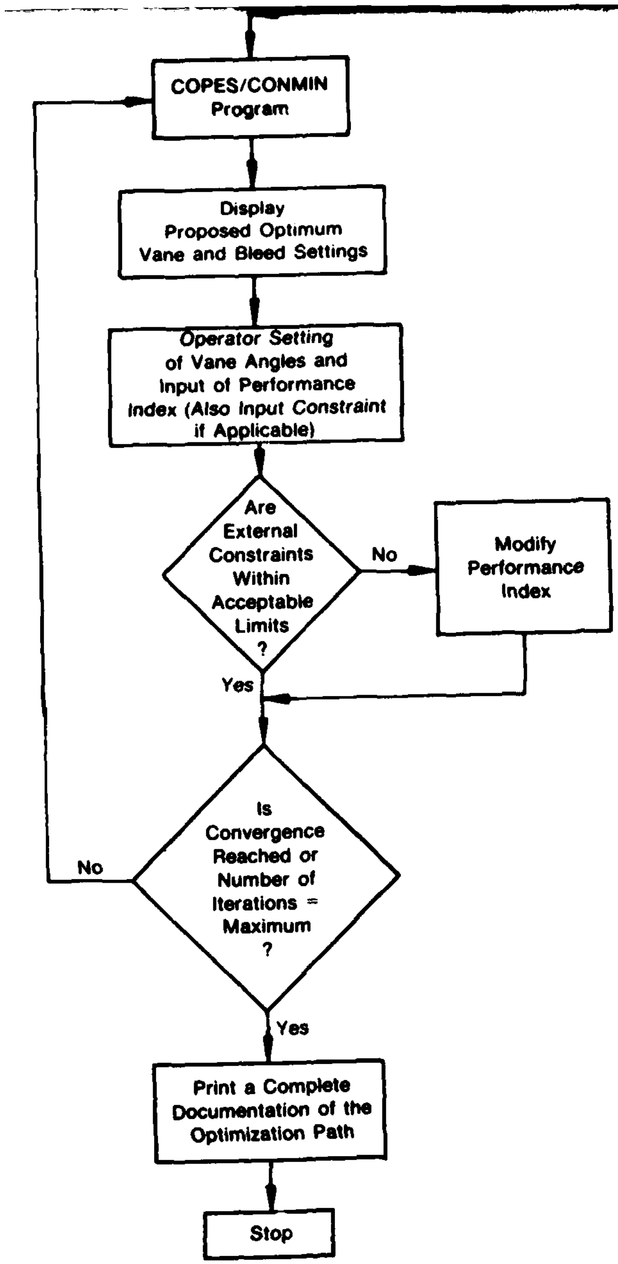


Figure 1. Vane Optimization Logic

2

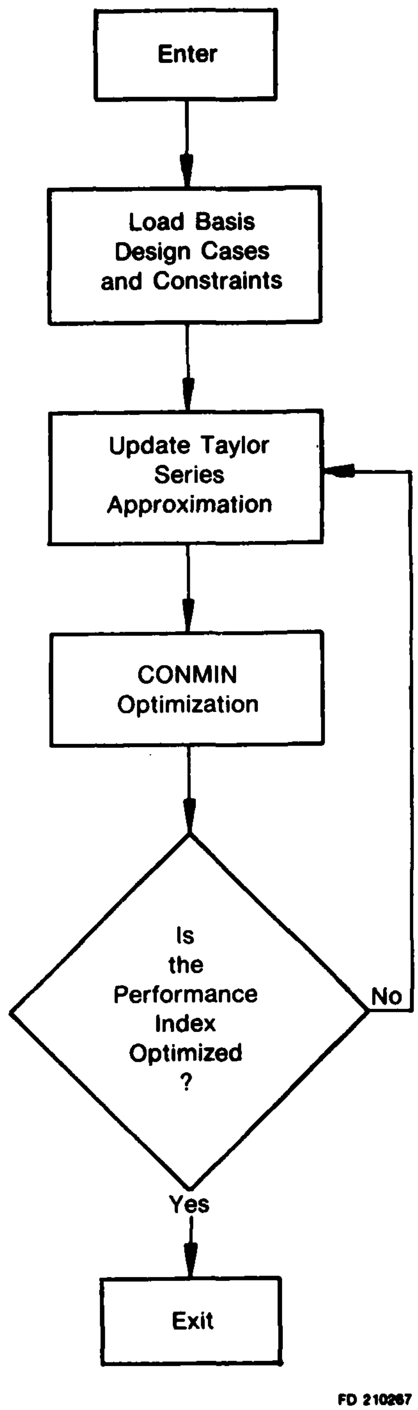


Figure 2. COPES/CONMIN Approximate Optimization Interface

COMPUTER TERMINAL DISPLAYS

The program title page, shown in Figure 3, will be automatically displayed on the terminal once the program has been loaded into the computer and the program is operational. Once the user initiates the program operation, a list of optimization goals will appear on the terminal for selection of the specific goal desired. A sample of the second display appears in Figure 4. Following selection of the desired goal, the interactive terminal will display the choice for verification. Typical versions of this display are shown in Figures 5 and 6.

The displays that follow on the terminal perform four functions, as described below:

1. Generate reminders of compressor operating conditions which may need to be held during the optimization process
2. Set upper and lower bounds for vane settings and performance constraints
3. Define the starting sequence of the test
4. Prompt the operator to make certain vane movements and perform efficiency and/or stall margin calculations.

Data entry displays will always repeat the entered information and await an accuracy approval or a correction command. Figures 7 through 16 show examples of how these functions are performed.

DATA STORAGE (ERROR RECOVERY)

The internal logic of COPES/CONMIM is incapable of "backing out" the previous input data if an error has been incurred. To minimize errors, the terminal input data, as interpreted by the computer, is redisplayed for verification prior to being stored. If an error is still made, a complete restart of the optimization logic is required. However, the compressor (or compressor model) need not be rerun. The computer program is reinitialized by the statement RFLAG=1. and the data values are re-entered exactly as they were originally input. Operator prompting will continue as during normal operation.

STARTING SEQUENCE OF TESTS

The basic aim of the COPES/CONMIM approximate optimization is to optimize an approximate surface by Taylor series expansion. To provide an initial model of this surface, a sequence of tests is performed wherein each vane and bleed setting is randomly varied. The minimum number of tests is N+1. Figure 17 presents the suggested starting sequence for up to four variable vanes and one bleed. Incremental vane and bleed settings are an operator input and may be chosen based on the expected performance sensitivity to vane angle. For high stage-loading compressors, a value between ± 1 and ± 2 deg is suggested. Note that to reduce experimental error, vanes are not reset between tests in this sequence.

```
A:  :  ::                  STATOR VANE OPTIMIZER
                     *********************
          PROTOTYPE SOFTWARE CAPABLE OF GUIDING THE OPTIMIZATION OF

          STATOR VANE AND BLEED SETTINGS IN A MULTI-STAGE COMPRESSOR

          PREPARED FOR THE AIR FORCE AERO PROPULSION LABORATORY

          UNDER CONTRACT F33615-79-C-2013

          BY: PRATT & WHITNEY AIRCRAFT GROUP
              GOVERNMENT PRODUCTS DIVISION



          PLEASE HIT RETURN TO CONTINUE
```

Figure 3. Title Page

```
A:   :  ::
  ---------------------------------------------------------------
             I OPTIMIZATION CONDITIONS I CONSTRAINTS I
NO I  GOAL   I RPMC  WC  PR   DVS  O.L. I S.M. I EFF  I
---+---------+--------------------------+------+-------
 1 I   EFF   I  X    -   -    X    -    I  -   I  -   I
 2 I   EFF   I  X    -   -    -    X    I  -   I  -   I
 3 I   EFF   I  -    X   X    -    -    I  -   I  -   I
 4 I   EFF   I  X    -   -    X    -    I MIN  I  -   I
 5 I   EFF   I  X    -   -    -    X    I MIN  I  -   I
 6 I   EFF   I  -    X   X    -    -    I MIN  I  -   I
 7 I  S.M.   I  X    -   -    X    -    I  -   I  -   I
 8 I  S.M.   I  X    -   -    -    X    I  -   I  -   I
 9 I  S.M.   I  -    X   X    -    -    I  -   I  -   I
10 I  S.M.   I  X    -   -    X    -    I  -   I MIN  I
11 I  S.M.   I  X    -   -    -    X    I  -   I MIN  I
12 I  S.M.   I  -    X   X    -    -    I  -   I MIN  I
13 I SM/BLD  I  X    X   -    -    -    I  -   I  -   I
14 I MAX WC  I  X    -   -    -    X    I MIN  I MIN  I
15 I MIN WC  I  X    -   -    -    X    I MIN  I MIN  I
16 I   PR    I  X    X   -    -    -    I MIN  I MIN  I
17 I   PR    I  X    -   -    -    X    I MIN  I MIN  I
ENTER NUMBER OF OPTIMIZATION GOAL DESIRED (INTEGER)
```

Figure 4. Optimization Goal Menu

```
A:  :  ::     YOU HAVE SELECTED TO OPTIMIZE EFFICIENCY HOLDING

          CORRECTED SPEED (RPMC) AND DISCHARGE VALUE SETTING (DVS) CONSTANT

          WITH NO CONSTRAINTS ON SURGE MARGIN
          IS THIS THE DESIRED OPTIMIZATION GOAL ? (Y/N)
```

Figure 5. Display for Optimization Goal 1

```
A:   :   ::     You Have Selected To Optimize Efficiency Holding

     Corrected Speed (RPMC) and Discharge Valve Setting (DVS) Constant

     While Constraining Surge Margin to a Minimum Valve
     Is This the Desired Optimization Goal ? (Y/N)
```

Figure 6. Display For Optimization Goal 4

```
A:  :  ::     ENTER VALUE FOR RPMC (INCLUDE DECIMAL POINT)

     YOU HAVE SELECTED TO HOLD RPMC CONSTANT AT A VALUE OF ,      0.0
     DO YOU AGREE? (Y/N)
```

Figure 7. Compressor Operating Condition Display

```
A:  :  ::A:  :  ::A:  :  ::     ENTER VALUE FOR DVS  (INCLUDE DECIMAL POINT)
1.0
     YOU HAVE SELECTED TO HOLD DVS  CONSTANT AT A VALUE OF ,      1.00000
     DO YOU AGREE? (Y/N)
```

Figure 8. Compressor Operating Condition Display

```
A:  :  ::A:  :  ::     HOW MANY VANES DO YOU WISH TO OPTIMIZE? (MAX=4)
4
     YOU HAVE CHOSEN TO OPTIMIZE 4 VANE ANGLES
     DO YOU AGREE? (Y/N)
```

Figure 9. Display for Input of Number of Variable Vanes

```
9:  :  :     ENTER LOWER BOUNDARY VALUE FOR VANE 1 (INCLUDE DECIMAL POINT)
-10.
     LOWER BOUND FOR VANE 1 IS    -10.000
     DO YOU AGREE? (Y/N)
```

Figure 10. Vane Setting Lower Bound Display

```
A:  :  ::     ENTER UPPER BOUNDARY VALUE FOR VANE 1 (INCLUDE DECIMAL POINT)
10.
     UPPER BOUND FOR VANE 1 IS    10.000
     DO YOU AGREE? (Y/N)
```

Figure 11. Vane Setting Upper Bound Display

```
A:  :  ::     ENTER LOWER BOUND VALUE FOR SM
5.
     ENTER UPPER BOUND VALUE FOR SM
50.
```

Figure 12. Performance Constraint Bounds Display

```
A:  :  ::     ENTER INITIAL VALUES FOR VANE ANGLES
     VANE 1 =  (INCLUDE DECIMAL POINT)
0.
     INITIAL VALUE FOR VANE 1 =      0.0
     DO YOU AGREE ? (Y/N)
Y
     VANE 2 =  (INCLUDE DECIMAL POINT)
0.
     INITIAL VALUE FOR VANE 2 =      0.0
     DO YOU AGREE ? (Y/N)
Y
     VANE 3 =  (INCLUDE DECIMAL POINT)
0.
     INITIAL VALUE FOR VANE 3 =      0.0
     DO YOU AGREE ? (Y/N)
Y
     VANE 4 =  (INCLUDE DECIMAL POINT)
0.
     INITIAL VALUE FOR VANE 4 =      0.0
     DO YOU AGREE ? (Y/N)
Y
```

Figure 13. Initial Vane Settings

```
A:   :   ::A:   :   ::      ENTER INCREMENTAL VANE ANGLE VALUE FOR INITIAL VANE SETTI
NGS
2.
```

Figure 14. Incremental Vane Angle for Initial Sequence of Tests

```
A:  :  ::A:  :  ::     SET VANE 1 TO    0.0  DEGREES

     SET VANE 2 TO    0.0  DEGREES

     SET VANE 3 TO    0.0  DEGREES

     SET VANE 4 TO    0.0  DEGREES

     HOLD RPMC CONSTANT AT A VALUE OF        0.0
     HOLD DVS  CONSTANT AT A VALUE OF        1.0000

     HAS FLUTTER OR EXCESSIVE VIBRATION OCCURRED AT THE REQUESTED POINT? (Y/N)
```

Figure 15. Vane and Compressor Rig Settings Display

```
A:  :  ::

      ENTER OBJECTIVE FUNCTION VALUE FOR EFFICIENCY
89.56

      ENTER CONSTRAINT VALUE FOR SURGE MARGIN
10.
      EFFICIENCY=     89.5600
      SURGE MARGIN=   10.0000
      CORRECT ? (Y/N)
```

Figure 16. Measured Performance Parameters Input

Test Number[1]	Vane Angle (deg)				Bleed Flow
	α_1	α_2	α_3	α_4	
1	0[2]	0	0	0	0
2	$0+\delta$[3]	0	0	0	0
3	$0+\delta$	$0+\delta$	0	0	0
4	$0+\delta$	$0+\delta$	$0+\delta$	0	0
5	$0+\delta$	$0+\delta$	$0+\delta$	$0+\delta$	0
6	$0+\delta$	$0+\delta$	$0+\delta$	$0+\delta$	$0+\beta$[4]

Notes:

1. Number of Tests is N+1, Where N Is the Number of Variable Vanes and Bleeds.
2. First Test Is Base, or Reference, Vane and Bleed Setting.
3. δ Is Operator Input of Incremental Vane Setting.
4. β Is Operator Input of Incremental Bleed Flow

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Figure 17. Initial Test Sequence

OPERATOR-IMPOSED CONSTRAINTS

During a test program, the operator will be monitoring a variety of strain gauge and blade flutter monitors. Any of these sensors may allow the operator to conclude that the test point vane settings may threaten the mechanical integrity of the compressor. Rejection of a test point should not automatically bring about the conclusion of the optimization attempts. The way to avoid this vane setting region (and discourage further movement in the hazardous direction) is by the artificial creation of a performance index deterioration or a constraint variable rise. A series of such actions by the operator will define to the program a wall or barrier that should not be crossed due to the optimum-seeking or constraint-avoidance logic. The technique employed in the vane optimization program is to change the performance index of the hazardous point by a factor of two. This is enacted by indicating that flutter or excessive vibration has occurred at the requested point.

STOPPING POINT

The stopping criteria used in this program include:

1. A minimum relative change in the objective function to indicate convergence

2. An absolute change in the objective function

3. A maximum number of iterations

4. Two consecutive approximate optimizations resulting in the same vane angle settings.

SECTION III

PROGRAM ORGANIZATION

GENERAL

The main program, as shown in Figure 18, consists simply of calls to the various subroutines used to initialize the input into the COPES/CONMIN optimization subroutine known as VOPT. Additionally, the main program contains logic for restarting the program at any point during the optimization. A description of each subroutine appears in the following paragraphs.

Subroutine PAGE1

Subroutine PAGE1 writes the title page to the screen and to the printer. The subroutine then waits until the operator depresses ENTER to go to subroutine GOAL.

Subroutine GOAL

Subroutine GOAL displays the listing of optimization goals and asks the operator to enter the value of the desired goal. It should be noted here that the value of the desired goal should be right adjusted in a two-column field. This means that numbers 1 through 9 should be entered as 01 through 09. Subroutine GOAL then writes to the screen the goal which the operator selected. When the operator is satisfied with the goal he has selected, subroutine GOAL then returns to the main program with the value of the desired goal.

Subroutine OPTCON

Subroutine OPTCON takes the value of the desired goal and prompts the operator for the necessary input to be used to write the COPES/CONMIN program input data.

Subroutine START

Subroutine START takes the initial X-vector and the number of design variables (NDV) and then creates NDV+1 X-vectors by perturbating the vane angles and bleed flow by some given amounts input by the operator. The subroutine writes these vectors into a file that will be read by COPES/CONMIN.

Subroutine SCFILE

Subroutine SCFILE takes all of the block data and all of the input from subroutine OPTCON and writes it into a file in right-adjusted fields of 10 columns each. COPES/CONMIN then reads this file in its optimization process.

Subroutine VOPT

Subroutine VOPT is the COPES/CONMIN optimization program.

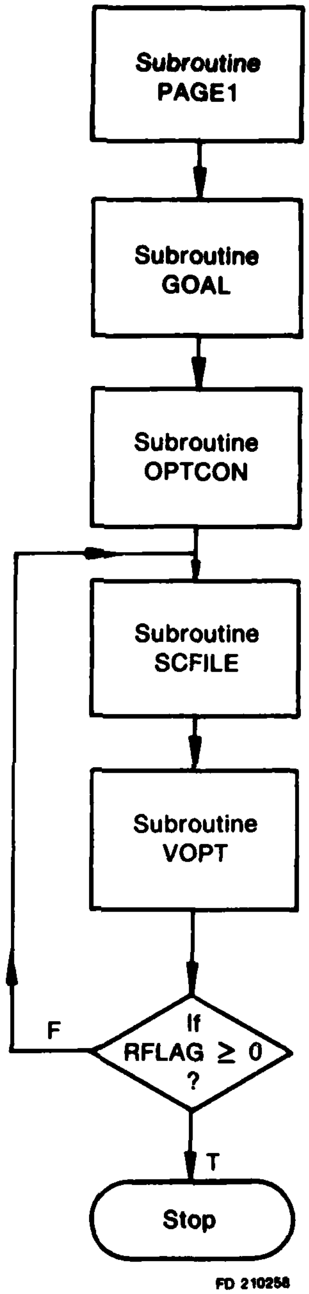

Figure 18. Program Organization

Subroutine ANALIZ

The COPES User's Manual (Reference 1) explains subroutine ANALIZ. An additional feature has been added to the usual ANALIZ output. When the program reaches a final solution, ANALIZ will write out the final results on the screen for the operator to see.

Subroutine ANALIZ includes a restart signal enabling the operator to restart the program without re-entering the data through subroutine OPTCON.

INITIALIZING INPUT-OUTPUT FILES

Before executing the vane optimization program, the user must allocate the following files:

File No.	*Program Name*	*Use*
5	ISCRX	Contains initial NDV+1 X-vectors
5	ISCRXF	Contains X-F pairs on a continuous basis
6	IPRINT	Output to printer
11	ISC	Scratch file which contains COPES/ CONMIN input data
12	ISCR1	Scratch file used by COPES/CONMIN program
13	ISCR2	Scratch file used by COPES/CONMIN program
15	IREAD	Input from terminal
16	IWRITE	Output from terminal

All files, except File 13 (ISCR2) should contain the following attributes: Block size — 6160, logical record length — 80, and record format — fixed block. File 13 should contain the following: block size — 6160, logical record length — 85, and record format — variable block span. Figure 19 shows a sample procedure for initializing these input-output files.

```
ATTRIB WORK BLKSIZE(6160) LRECL(80) RECFM(F B)
ATTRIB WORT BLKSIZE(6160) LRECL(85) RECFM(V B S)
/*        ALLOCATE DATASETS

/*  FILE IREAD
ALLOC DD(FT15F001) DSN(*) REUSE
/*  FILE IWRITE
ALLOC DD(FT16F001) DSN(*) REUSE
/*  FILE ISC
ALLOC DD(FT11F001) DSN('XXXXXXX.FILE.F11.DATA') NEW SP(1,1) TRACKS -
  USING(WORK) REUSE
/*  FILE ISCR1
ALLOC DD(FT12F001) DSN('XXXXXXX.FILE.F12.DATA') NEW SP(1,1) TRACKS -
  USING(WORK) REUSE
/*  FILE ISCR2
ALLOC DD(FT13F001) DSN('XXXXXXX.FILE.F13.DATA') NEW SP(1,1) TRACKS -
  USING(WORT) REUSE
/*  FILE IFPRINT
ALLOC DD(FT06F001) SYSOUT(&CLASS) REUSE
/*  FILES ISCRX AND ISCRXF
ALLOC DD(FT05F001) DSN('XXXXXXX.FILE.F05.DATA') NEW SP(1,1) TRACKS -
  USING(WORK) REUSE
```

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Figure 19. Initialization Procedure

SECTION IV

COPES/CONMIN DESCRIPTION

THEORY

CONMIN (Reference 2) represents a general purpose optimization program designed primarily for the optimization of constrained functions. The basic optimization algorithm used in CONMIN employs a direct search technique based on the method of feasible directions described in Reference 3. The algorithm has been modified to improve efficiency and numerical stability and to solve optimization problems in which one or more constraints are initially violated (Reference 4). In a subroutine format, CONMIN can be called by a user-supplied main program. The user should supply a main program containing the analysis, constraints, equations, and objective function. Therefore, if an existing analysis program is used, the analysis portion may need some reorganization, and constraint equations must be prepared in accordance with CONMIN requirements.

In order to eliminate this inconvenience, a control program known as COPES (a FORTRAN Control Program for Engineering Synthesis) was developed by the same author who developed CONMIN. COPES combined with CONMIN enables the use of CONMIN as a "black box" for optimization in automated design synthesis. The user need only provide a FORTRAN analysis program for the particular problem being considered. COPES simply calls the user-supplied program written according to a simple set of guidelines. The capabilities of COPES/CONMIN include:

1. Simple analysis
2. Optimization
3. Sensitivity analysis
4. Two-variable function space generation
5. Optimum sensitivity analysis
6. Approximate optimization.

Particularly, approximate optimization provides the most suitable technique for the compressor vane optimization problem where the number of test points needed to perform the optimizaton is a limiting factor. The basic idea of approximate optimization technique involves sequentially optimizing an approximate design function surface generated from available information. In this program, the design surface represents a function of efficiency and stall margin. At the end of the optimization, the design surface is updated with information from a precise analysis, or test, at a new set of design variables. This new approximate problem is then optimized, followed by a new precise analysis. This process repeats until the solution has converged.

COPES/CONMIN possesses the capability to do up to a second-order approximation. If excessive data are available, the extra data are applied to a weighted least-square fit, rather than in obtaining higher order approximations. If a quadratic design surface were assumed, the second-order approximation would be precise. If the problem at hand can be approximated by a quadratic function, this method becomes feasible.

An outline of the sequential approximation approach (Reference 5) appears below. The second-order approximate form comes from a Taylor series expansion of any function, noted as

$$\Delta f \simeq \nabla f \cdot \Delta \bar{x} + \tfrac{1}{2} \Delta \bar{x}^T [H] \Delta \bar{x} \qquad (1)$$

where,

$$\Delta \bar{x} = \bar{x} - \bar{x}^{o}$$

$$\Delta f = f - f^{o}$$

$$\bar{\nabla} f = \left[\frac{\partial f}{\partial x_1} \frac{\partial f}{\partial x_2} \; \cdots \; \frac{\partial f}{\partial x_n} \right]^T \tag{2}$$

$$[\,H\,] = \begin{bmatrix} \dfrac{\partial^2 f}{\partial x^2_1} & \dfrac{\partial^2 f}{\partial x_1 \partial x_2} & \cdots & \dfrac{\partial^2 f}{\partial x_1 \partial x_n} \\ & \dfrac{\partial^2 f}{\partial x^2_2} & & \\ & & \ddots & \\ \text{Symmetric} & & & \dfrac{\partial^2 f}{\partial x^2_n} \end{bmatrix}$$

n = number of design parameters

x^o = nominal design analyzed to yield f^o.

Equation 1 holds for both objective and constraints. The unknowns are:

$$\frac{\partial f}{\partial x_1} \; \cdots \; \frac{\partial f}{\partial x_n} \quad \text{and} \quad \frac{\partial^2 f}{\partial x^2_1} \; \cdots \; \frac{\partial^2 f}{\partial x^2_n}$$

for a total of ($\ell = n + n\,(n+1)/2$). Since one analysis is required for the nominal design, a total of ($\ell+1$) test points are required to determine the unknowns, ($\bar{\nabla} f$) and [H]. If more than ($\ell+1$) tests are available, a weighted least-square fit is used.

Since previous test data show that efficiency and stall margin can be closely approximated locally in quadratic form in terms of the vane angle, quadratic approximation in the compressor vane optimization is considered quite reasonable. The fact that analysis data obtained in one optimization are used to improve the design surface for subsequent optimization enables the test engineer to choose a new test point; i.e., the result obtained in one optimization becomes the recommended test point and the test result obtained at this point is added to the new approximate optimization problem.

Numerical experience shows that a full quadratic approximation is not necessarily required even when the design function surface is quadratic. An approximation that includes up to the diagonal terms of the Hessian matrix in Equation 1 is quite accurate for a quadratic surface. This approximation requires a minimum of 2n+1 test points (n tests for linear terms, n tests for diagonal terms of the Hessian matrix, and one test for the initial design point). If more than 2n+1 designs are available, they are used in a weighted least-square fit. The COPES/CONMIN program provides the user with the option to use the approximate design surface constructed using only up to the Hessian diagonal terms in the approximate optimization. Because this technique can significantly reduce the number of expensive test points without losing the quality of the solution, it is used in the compressor vane optimization.

INTERFACING REQUIREMENTS

The COPES/CONMIN computer program is set up to make multiple passes through a subroutine called ANALIZ. In the conventional design process, this subroutine will contain an evaluation of the performance index being optimized and the constraint parameter for a given set of vane angles. The vane optimization program logic will specify a new vane setting to the operator and take care of recording new data from operator entries in the proper format. Command will be transferred back to the program and execution will continue with the newly supplied information. The method of interfacing described above required the absolute minimum level of COPES/CONMIN code change.

Another very important interfacing objective is to reformat operator input data to be compatible with the existing COPES input handling routine COPE01. Again, the driving force behind this objective is the desire to retain as much of the original COPES code as possible.

The COPES User's Manual (Reference 1) contains a detailed description of the complete input file requirements for the full variety of deck options. Figure 20 presents a listing of the card images of input data relevant to the COPES/CONMIN approximate optimization logic within the compressor vane optimization program.

```
ISN 0002            BLOCK DATA
              C
ISN 0003            COMMON /BDATA/ NCALC,NSV,NDVAR,IPNPUT,IFDDG,
                  1                IPRNT,ITMAX,NSCAL,ITRM,LINOBJ,NACMX1,NFDG,
                  2                FDCH,FDCHM,CT,CTMIN,CTL,CTLMIN,THETA,
                  3                DELFUN,DABFUN,ALPHAX,ABOBJ1,
                  4                NF,NXA,INCM,IPAPRX,
                  5                NFMAX,JNCM,INXLOC,INFLOC,MAXTRM
ISN 0004            DATA   NCALC,NSV,NDVAR,IPNPUT,IFDDG,
                  1        IPRNT,ITMAX,NSCAL,ITRM,LINOBJ,NACMX1,NFDG,
                  2        FDCH,FDCHM,CT,CTMIN,CTL,CTLMIN,THETA,
                  3        DELFUN,DABFUN,ALPHAX,ABOBJ1,
                  4        NF,NXA,INCM,IPAPRX,
                  5        NFMAX,JNCM,INXLOC,INFLOC,MAXTRM/
                  *        6,0,0,1,0,
                  1        5,20,0,3,0,0,0,
                  2        .01,.001,-.05,.004,-.01,.001,1.0,
                  3        .001,0.0,.1,.1,
                  4        0,0,0,1,
                  5        0,0,0,0,2/
ISN 0005            COMMON /UNIT/IREAD,IWRITE,IPRINT,ISCRX,ISCRXF,ISC
ISN 0006            DATA IREAD,IWRITE,IPRINT,ISCRX,ISCRXF,ISC/15,16,6,5,5,11/
ISN 0007            COMMON /NAME/NAME(7)
ISN 0003            DATA NAME/4HRPMC,4HWC  ,4HPR  ,4HDVS ,4HOL  ,4HSM  ,4HEFF /
              C
ISN 0009            END
```

Figure 20. COPES/CONMIN Input Data Relevant to the Compressor Vane Optimization Program

SECTION V

PROGRAM DEMONSTRATION

COMPRESSOR SIMULATION

In order to demonstrate the vane optimization software, a stage-by-stage compressor model has been implemented into a computer program. The characteristics of normalized pressure rise and temperature rise as functions of normalized airflow and vane angle are representative of an eleven stage, four variable vane compressor. The stall line used to provide the compressor performance appears in Figure 21. The illustrations shown in Figures 22 through 25 depict the efficiency and stall margin variations with vane angle computed at two degree increments, while holding speed and discharge area constant.

It should be noted that efficiency and stall margin calculations have an accuracy of ±0.05%, which may be attributed to the following factors:

1. Stage characteristic modeling
2. Interpolations between stage characteristics
3. Flow balance iterations.

Thus, the performance calculations from this model can be considered to have an inherent ±0.05% measurement error.

Input to the stage-by-stage compressor model is read using a FORTRAN-NAMELIST statement. Each input case must begin with $PWA punched starting in Column 2 to prepare the program to read the input. The input then follows, punched in FORTRAN-NAMELIST format, with each item separated with a comma and with the input list concluded by $END. No input may be entered in Column 1. The $END card initiates execution. The input parameters are as follows:

Parameter	*Default Value*	*Description*
NIN	5	Input file number
NOUT	6	Output file number
NOUTN	0	Optional output file number
CASE*	0	Case number
VANE1	0	Vane angle 1
VANE2	0	Vane angle 2
VANE3	0	Vane angle 3
VANE4	0	Vane angle 4
STOP	0	Stop signal
WCINLT	Converged values from previous case or 81.5	Inlet corrected airflow
GUES	Converged values from previous case or 0.94	M-line guess

The converged values for the independent variables WCINLT and GUES from a successfully closed point can be used as guesses for the **next** point. If no guess is supplied by the user for the first run, the values 81.5 and 0.94 will be used as guesses for WCINLT and GUES, respectively. On succeeding points, if no guesses are given, the converged values from the last point are used. The M-line guess should be approximately 1.0.

*CASE is automatically incremented with each set of input read, unless reloaded.

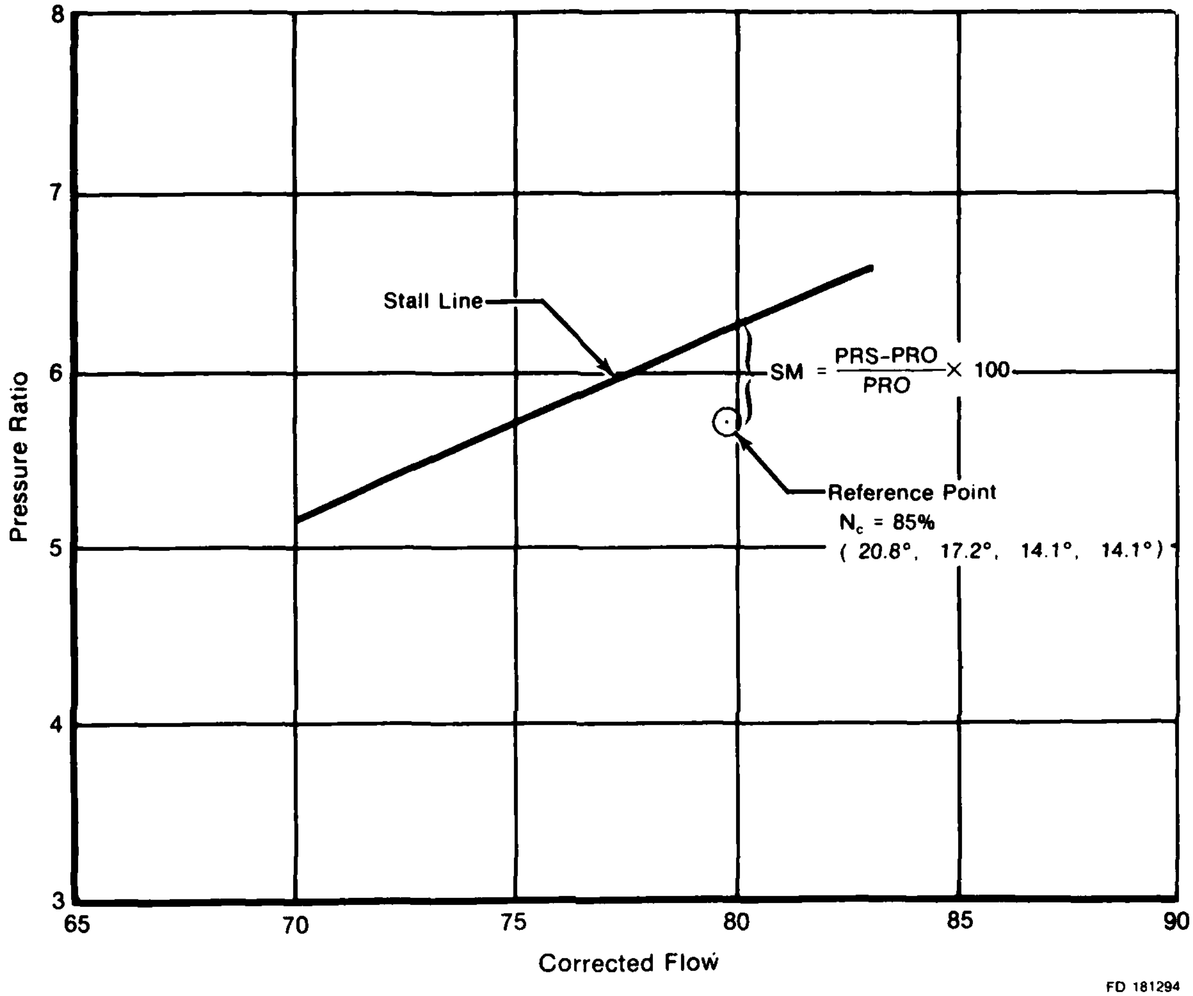

Figure 21. Compressor Model Performance Map

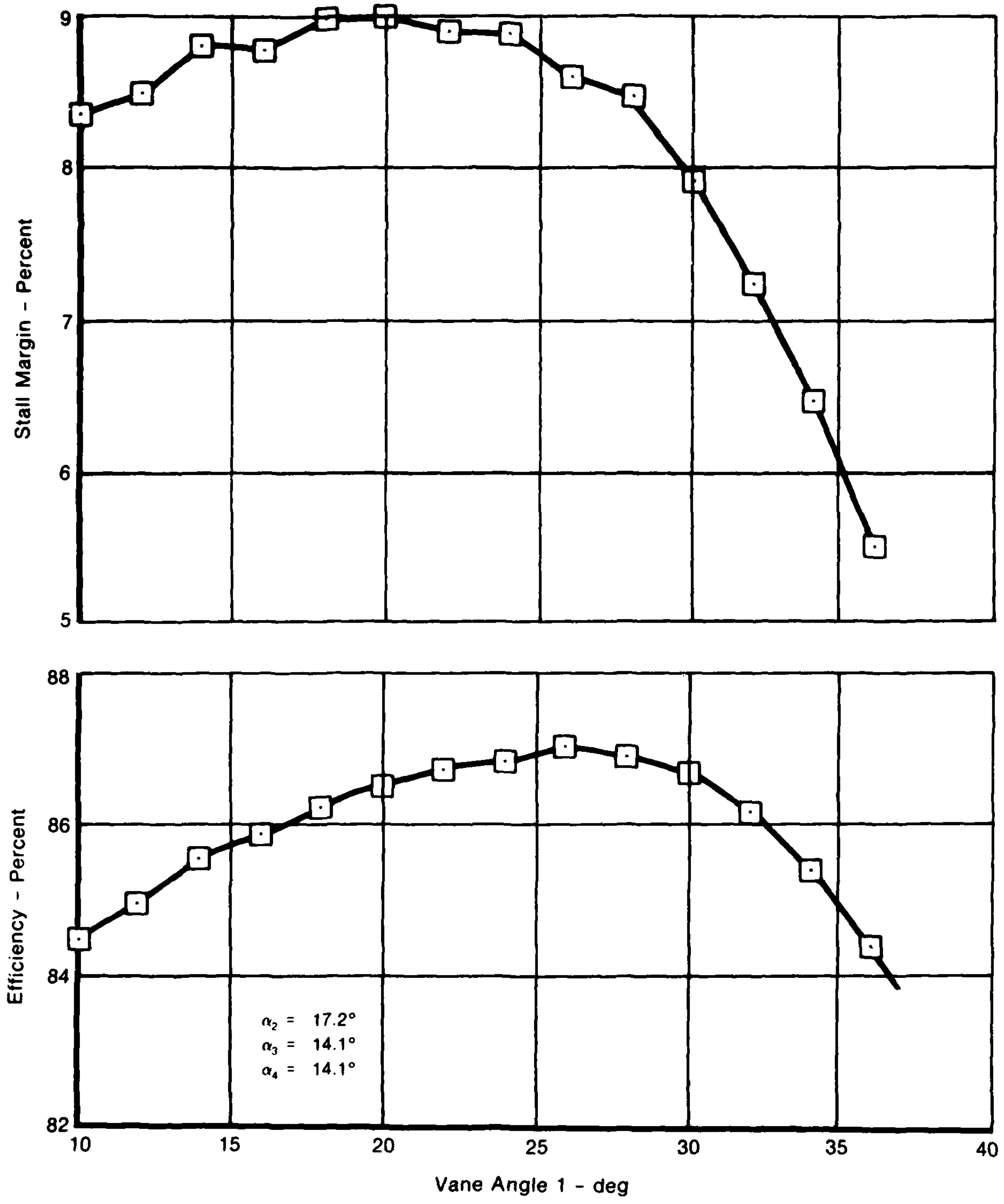

Figure 22. Efficiency and Stall Margin Variation With Variable Vane 1

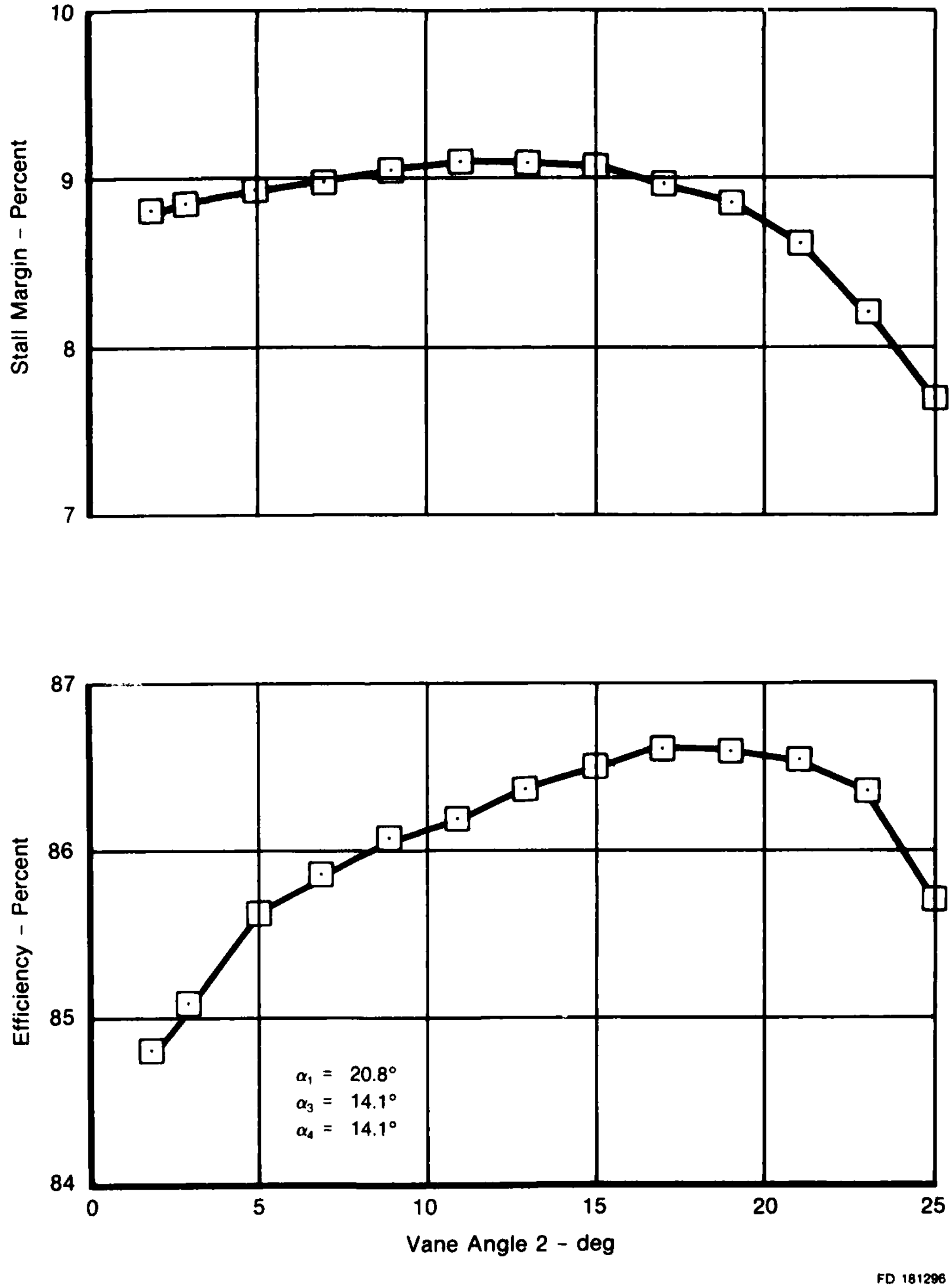

Figure 23. Efficiency and Stall Margin Variation With Variable Vane 2

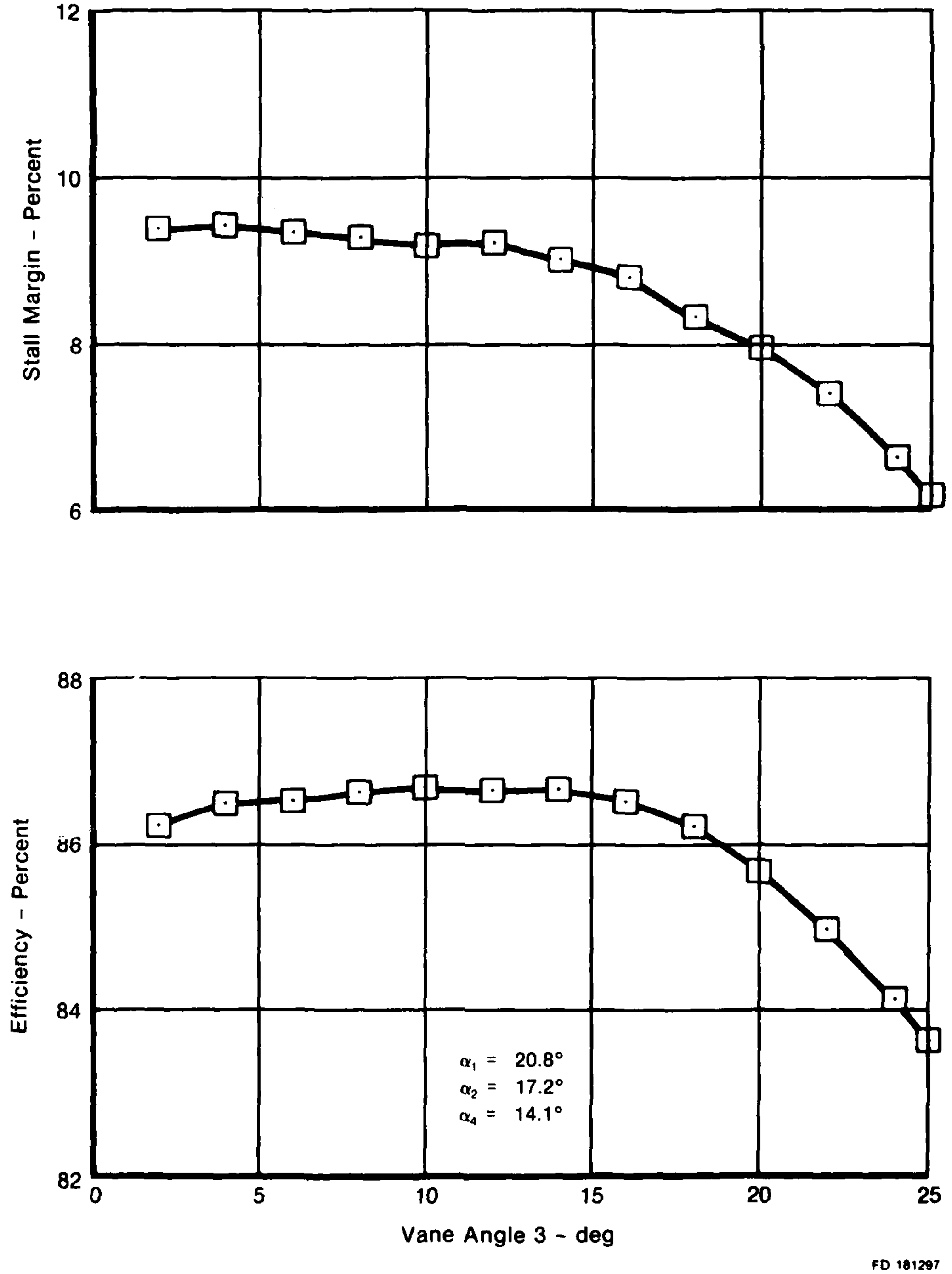

Figure 24. Efficiency and Stall Margin Variation With Variable Vane 3

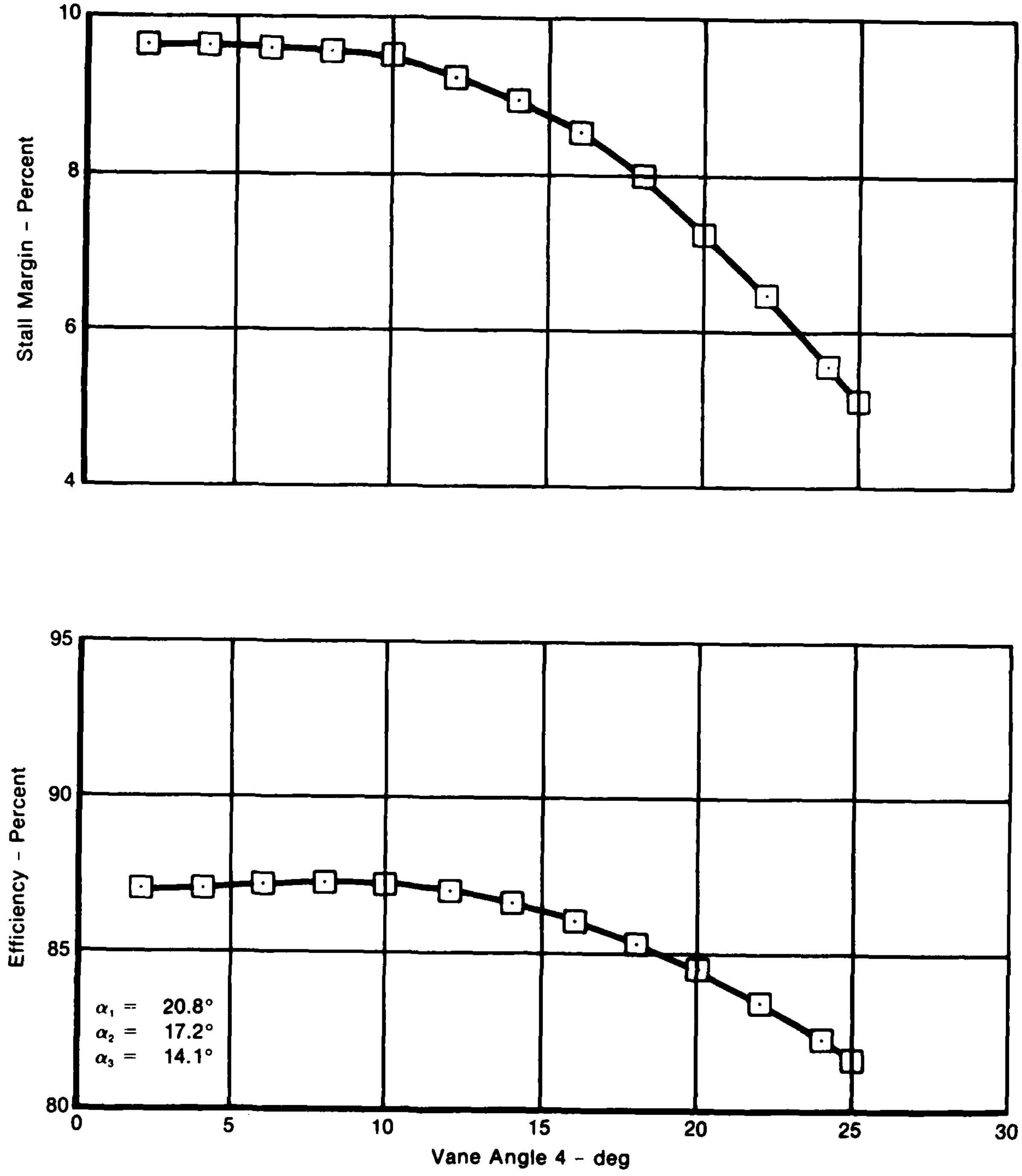

Figure 25. Efficiency and Stall Margin Variation With Variable Vane 4

All input is initially read and written to input files 5 and 6. However, the file number can be changed by the user by changing the input variables NIN and NOUT. It is also possible to direct the output to two different output files by specifying another file number NOUTN. If this variable is omitted, output will be directed to only one file, specified by NOUT. A STOP = −1.0 should be included in the last input case to terminate the program. If it is left out or set to a value other than −1.0, the program will look for another input case to follow. The output parameters are:

Parameter	*Description*
VANE1	Input vane angle 1
VANE2	Input vane angle 2
VANE3	Input vane angle 3
VANE4	Input vane angle 4
SM	Surge margin
EFF	Adiabatic efficiency
PR	Pressure ratio
WC	Corrected airflow

The following paragraphs detail the results for various optimization goals using the optimization program on the stage-by-stage compressor simulation. A summary of the problems solved and the resulting solutions is presented in Table 1. Appendices A through I contain output information for the sample problems.

UNCONSTRAINED OPTIMIZATION

Example 1:

The objective of this problem involves the optimization of four variable vanes for maximum efficiency, while holding speed and discharge area constant (Optimization Goal 1). The optimization problem can be formulated as

$$\max_{\alpha_1,\alpha_2,\alpha_3,\alpha_4,N,\ AREA} \eta(\alpha_1,\alpha_2,\alpha_3,\alpha_4,\ N,\ AREA) \tag{3}$$

subject to

a. $\alpha_{1_{min}} \leq \alpha_1 \leq \alpha_{1_{max}}$ $\qquad$ $\alpha_{2_{min}} \leq \alpha_2 \leq \alpha_{2_{max}}$

$\alpha_{3_{min}} \leq \alpha_3 \leq \alpha_{3_{max}}$ $\qquad$ $\alpha_{4_{min}} \leq \alpha_4 \leq \alpha_{4_{max}}$

b. $AREA = AREA_0 = 76.779$

c. $N = N_0 = 5567.5$ rpm (%Nc = 85)

The upper and lower bounds imposed on vane travel appear in Table 2.

With initial vane settings of $(\alpha)_1$=29 deg, $(\alpha)_2$=18 deg, $(\alpha)_3$=15 deg, and $(\alpha)_4$=11 deg, and initial efficiency of 87.14%, convergence to the optimum efficiency of 87.53% occurs in 15 tests (10 iterations). Optimum vane angle settings become $(\alpha)_1$= 25.59 deg, $(\alpha)_2$=17.99 deg, $(\alpha)_3$=12.17 deg, and $(\alpha)_4$=7.47 deg. Note that the incremental vane angle variation used for the initial sequence of 5 tests is −2 deg. Appendix A details the optimization results for Example 1.

TABLE 1. SUMMARY OF OPTIMIZATION EXAMPLES SOLVED

Example Number	*Optimization Goal*	α_1	α_2	α_3	α_4	*Pressure Ratio*	*Corrected Flow (Wc)*	*Efficiency (%)*	*Stall Margin (%)*	*Test Point Number at Optimum*
1	Maximize η	25.59	17.99	12.17	7.47	—	—	87.53	9.32	15
2	Maximize η	24.55	17.78	11.68	7.76	—	—	87.52	9.45	15
3	Maximize SM	18.94	10.71	5.00	5.00	—	—	86.73	10.30	22
4	Maximize η with SM$\geq$10.0	23.73	15.58	7.29	5.37	—	—	87.39	10.00	10
5	Maximize η with SM$\geq$10.0	22.64	14.72	9.24	5.00	—	—	87.38	9.98	15
6	Maximize SM with $\eta\geq$87.3	22.34	14.54	8.87	5.00	—	—	87.32	10.09	21
7	Maximize Wc with $\eta\geq$87.0 and SM$\geq$8.5	20.08	10.31	5.85	5.00	—	84.39	86.81	10.19	14
8	Minimize Wc with $\eta\geq$87.0 and SM$\geq$8.5	27.93	19.92	15.72	9.54	—	77.65	87.20	8.47	15
9	Maximize PR with $\eta\geq$87.0 and SM$\geq$8.5	21.06	10.17	5.01	5.01	6.105	—	86.82	10.15	15

TABLE 2. VANE TRAVEL LIMITS

	α_1	α_2	α_3	α_4
Lower Bound	10	5	5	5
Upper Bound	35	25	25	25

Example 2:

This problem duplicates Example 1, except that the initial sequence is modified. Design of the example evaluates the effect of randomly selecting the initial test points.

With initial vane angles set at $(\alpha)_1$=18 deg, $(\alpha)_2$=10 deg, $(\alpha)_3$=5 deg, and $(\alpha)_4$=5 deg, and efficiency (η) = 86.60%, convergence occurs in 19 tests, although optimization was reached at the fifteenth test point. Optimum vane angles become $(\alpha)_1$=24.55 deg, $(\alpha)_2$=17.78 deg, $(\alpha)_3$=11.68 deg, and $(\alpha)_4$=7.76 deg at an efficiency of 87.52%. A 2 deg incremental vane angle variation was used for the initial sequence of tests in this example. Appendix B lists the optimization results for Example 2.

The fact that the optimum efficiency duplicates that found in the first example indicates that the analysis is relatively insensitive to starting point. The optimum vane angle settings, however, are slightly different for the two examples, although they are within 1 deg of each other. The compressor model exhibits a very flat region near the optimum with little gain in efficiency. This fact also attributed to the additional tests required in the second example to meet the convergence criteria after the optimum was reached.

Example 3:

The objective of Example 3 is to maximize stall margin while holding speed and discharge area constant (Optimization Goal 7). The problem can be expressed as

$$\max_{\alpha_1, \alpha_2, \alpha_3, \alpha_4} SM \tag{4}$$

With the same initial vane settings and initial test sequence as in Example 1, the optimum settings were obtained after 22 test points. The vane settings are $(\alpha)_1$=18.94 deg, $(\alpha)_2$=10.71 deg, $(\alpha)_3$=5.00 deg, and $(\alpha)_4$=5.00 deg with an optimum stall margin at 10.30%. The efficiency at these vane settings is 86.73%. Results for this problem appear in Appendix C.

CONSTRAINED OPTIMIZATION

Example 4:

The function maximized in Examples 1 and 2 is now solved with stall margin constrained above a given level (Optimization Goal 4). The stall margin at the optimum efficiency conditions in the previous examples are 9.32 and 9.45%, respectively. Mathematically, this problem can be stated as

$$\max_{\alpha_1, \alpha_2, \alpha_3, \alpha_4} \eta \quad \text{subject to } SM \geq 10.0\% \tag{5}$$

With the same initial vane settings and initial test conditions as Example 1, a converged solution results in 14 tests at $(\alpha)_1$=23.73 deg, $(\alpha)_2$=15.58 deg, $(\alpha)_3$=7.29 deg, and $(\alpha)_4$=5.37 deg with an efficiency at 87.39% and stall margin of 10.00%. Note that the optimization algorithm brought the efficiency down from the 87.5% values in Examples 1 and 2 to meet the stall margin constraint. Appendix D presents the results for this example.

Example 5:

The same problem as Example 4 is considered, except that the influence of measurement error on convergence ability is examined. In addition to the ±0.05% noise in the stage-by-stage model, the random errors shown in Table 3 are added to the performance values. The errors are normally distributed with a standard deviation of 0.05.

Appendix E details the results for this example. The optimum was reached in 15 tests at $(\alpha)_1$=22.64 deg, $(\alpha)_2$=14.72 deg, $(\alpha)_3$=9.24 deg, and $(\alpha)_4$=5.00 deg with efficiency at 87.38% and stall margin at 9.98%. The efficiency and stall margin are essentially the same as the values obtained in Example 4 and the vane angles are within 2.0 deg.

Example 6:

This problem represents the constrained version of Example 3. Here, it is desired to maximize stall margin while maintaining efficiency above a given level (Optimization Goal 10). Mathematically, this can be represented as

$$\max_{\alpha_1, \alpha_2, \alpha_3, \alpha_4} SM \text{ subject to } \eta \geq 87.3\% \tag{6}$$

Appendix F details the results of this optimizaton with start settings for vane angle as in Example 3. The optimum solution was reached after 21 tests at vane settings of $(\alpha)_1$=22.34 deg, $(\alpha)_2$=14.54 deg, $(\alpha)_3$=8.87 deg, and $(\alpha)_4$=5.00 deg with an optimum stall margin of 10.09% and an efficiency of 87.32%. Here, the optimization algorithm brought the stall margin down from 10.30% obtained in Example 3 to meet the efficiency constraint.

TABLE 3. MEASUREMENT ERRORS FOR EXAMPLE 5

Test Point Number	*Efficiency Error (%)*	*Stall Margin Error (%)*
1	0.04	−0.04
2	−0.02	0.04
3	−0.03	0.09
4	0.03	−0.02
5	0.09	0.06
6	−0.02	−0.08
7	0.00	0.04
8	−0.06	0.00
9	0.01	0.01
10	0.02	0.00
11	0.06	0.08
12	0.02	0.00
13	−0.03	0.07
14	−0.04	−0.02
15	0.02	0.07
16	0.11	−0.01
17	0.01	−0.03
18	0.07	−0.02
19	−0.04	−0.06
20	0.05	−0.05
21	0.08	0.03
22	−0.03	0.04

Example 7:

The next two examples establish the maximum and minimum flow points to provide the maximum flow range. In addition to airflow requirements, performance constraints of minimum acceptable efficiency and stall margin also define the flow range. Thus, their evaluations must be considered for each geometry setting. For this example, Optimization Goal 14 is defined as

$$\max_{\alpha_1,\ \alpha_2,\ \alpha_3,\ \alpha_4} \quad Wc \quad \text{with } \eta \geq 87.0\% \text{ and } SM \geq 8.5\% \tag{7}$$

subject to the conditions of holding speed constant at 5567.5 rpm and discharge valve area at 76.779.

Appendix G details the results. For the initial test sequence used in Examples 1 and 3 through 6, the optimization algorithm converged to the maximum flow in 14 tests at a corrected flow of 84.39 lbm/sec with an efficiency of 86.81% and stall margin of 10.19%. Optimum vane settings are $(\alpha)_1$=20.08 deg, $(\alpha)_2$=10.31 deg, $(\alpha)_3$=5.85 deg, and $(\alpha)_4$=5.00 deg.

Example 8:

This example deals with minimizing corrected airflow (Optimization Goal 15), mathematically formulated as

$$\min_{\alpha_1,\, \alpha_2,\, \alpha_3,\, \alpha_4} \quad Wc \quad \text{with } \eta \geq 87.0\% \text{ and SM} \geq 8.5\% \tag{8}$$

subject to holding speed and discharge area constant.

Results for this example appear in Appendix H. With the same initial test sequence as in Example 7, the minimum corrected airflow of 77.65 lbm/sec was reached in 15 tests at $(\alpha)_1$=27.93 deg, $(\alpha)_2$=19.92 deg, $(\alpha)_3$=15.72 deg, and $(\alpha)_4$=9.54 deg with an efficiency of 87.20% and stall margin of 8.47%.

Example 9:

As a final example, the pressure ratio is maximized at constant speed and discharge area while maintaining minimal acceptable values of efficiency and stall margin (Optimization Goal 17). The problem solution can be stated as

$$\max_{\alpha_1,\, \alpha_2,\, \alpha_3,\, \alpha_4} \quad PR \quad \text{with } \eta \geq 87.0\% \text{ and SM} \geq 8.5\% \tag{9}$$

Results of performing the optimization appear in Appendix I. This example converged in 15 tests at a maximum pressure ratio of 6.105 with an efficiency of 86.82% and stall margin of 10.15%. The optimum vane settings are $(\alpha)_1$=21.06 deg, $(\alpha)_2$=10.17 deg, $(\alpha)_3$=5.01 deg, and $(\alpha)_4$=5.01 deg.

SECTION VI

IDENTIFICATION

Pratt & Whitney Aircraft Group, Government Products Division uses a "Customer Computer Deck" identification system that appears on the outline sheet as

CCD XXXX-XX.X
DATE XX/XX/XX

The first four digits correspond to the compressor vane and bleed optimization program. If another optimization method is developed or studied which does not replace or supercede the original method, a new four-digit number will be used.

Changes in the demonstrator compressor model performance will be related in different dash numbers. The dash number of the original deck will be zero.

The decimal number will be used to reflect all deck changes which do not affect the basic optimization method or compressor model. This includes correcting any program errors.

Any deck change causing a change to the dash number or decimal part of the CCD number will change the previous date of the deck.

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REFERENCES

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3. Zoutendijk, G., *Method of Feasible Direction*, Elsevier Publishing Company, Amsterdam, 1960.

4. Vanderplaats, G. N. and F. Moses, "Structural Optimization by Methods of Feasible Directions," *J. Computers and Structures*, Vol. 3, Pergamon Press, July 1973.

5. Vanderplaats, G. N., "Approximate Concepts for Numerical Airfoil Optimization," NASA Technical Paper 1370, March 1979.

STATOR VANE OPTIMIZER
****
PROTOTYPE SOFTWARE CAPABLE OF GUIDING THE OPTIMIZATION OF

STATOR VANE AND BLEED SETTINGS IN A MULTI-STAGE COMPRESSOR

PREPARED FOR THE AIR FORCE AERO PROPULSION LABORATORY

UNDER CONTRACT F33615-79-C-2013

BY: PRATT & WHITNEY AIRCRAFT GROUP
GOVERNMENT PRODUCTS DIVISION

PLEASE HIT RETURN TO VIEW OPTIMIZATION GOAL MENU

NO	GOAL	OPTIMIZATION CONDITIONS RPMC	WC	FR	DVS	O.L.	CONSTRAINTS S.M.	EFF
1	EFF	X	-	-	X	-	-	-
2	EFF	X	-	-	-	X	-	-
3	EFF	-	X	X	-	-	-	-
4	EFF	X	-	-	X	-	MIN	-
5	EFF	X	-	-	-	X	MIN	-
6	EFF	-	X	X	-	-	MIN	-
7	S.M.	X	-	-	X	-	-	-
8	S.M.	X	-	-	-	X	-	-
9	S.M.	-	X	X	-	-	-	-
10	S.M.	X	-	-	X	-	-	MIN
11	S.M.	X	-	-	-	X	-	MIN
12	S.M.	-	X	X	-	-	-	MIN
13	SM/BLD	X	X	-	-	-	-	-
14	MAX WC	X	-	-	-	X	MIN	MIN
15	MIN WC	X	-	-	-	X	MIN	MIN
16	FR	X	X	-	-	-	MIN	MIN
17	FR	X	-	-	-	X	MIN	MIN

YOU HAVE SELECTED TO OPTIMIZE EFFICIENCY HOLDING

CORRECTED SPEED (RPMC) AND DISCHARGE VALVE SETTING (DVS) CONSTANT

WITH NO CONSTRAINTS ON SURGE MARGIN
HOLD RPMC CONSTANT AT 5567.500
HOLD DVS CONSTANT AT 76.779
OPTIMIZING 4 VANE ANGLES
LOWER BOUND FOR VANE 1 IS 10.000
DO YOU AGREE? (Y/N)
LOWER BOUND FOR VANE 2 IS 5.000
DO YOU AGREE? (Y/N)
LOWER BOUND FOR VANE 3 IS 5.000
DO YOU AGREE? (Y/N)
LOWER BOUND FOR VANE 4 IS 5.000
DO YOU AGREE? (Y/N)
UPPER BOUND FOR VANE 1 IS 35.000
DO YOU AGREE? (Y/N)
UPPER BOUND FOR VANE 2 IS 25.000
DO YOU AGREE? (Y/N)

UPPER BOUND FOR VANE 3 IS 25.000
DO YOU AGREE? (Y/N)
UPPER BOUND FOR VANE 4 IS 25.000
DO YOU AGREE? (Y/N)
INCREMENTAL VANE ANGLE VALUE FOR INITIAL VANE SETTING IS -2.00

```
TITLE:
**********************************************************

CONTROL PARAMETERS;
CALCULATION CONTROL,                        NCALC =    6
NUMBER OF GLOBAL DESIGN VARIABLES,           NDV =    4
NUMBER OF SENSITIVITY VARIABLES,             NSV =    0
NUMBER OF FUNCTIONS IN TWO-SPACE,          N2VAR =    0
NUMBER OF APPROXIMATING VAR.              NXAPRX =    4
INPUT INFORMATION PRINT CODE,             IPNPUT =    1
DEBUG PRINT CODE,                          IPDBG =    0

CALCULATION CONTROL, NCALC
VALUE   MEANING
  1     SINGLE ANALYSIS
  2     OPTIMIZATION
  3     SENSITIVITY
  4     TWO-VARIABLE FUNCTION SPACE
  5     OPTIMUM SENSITIVITY
  6     APPROXIMATE OPTIMIZATION


* * OPTIMIZATION INFORMATION

GLOBAL VARIABLE NUMBER OF OBJECTIVE            =    7
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION) =  0.1000E+01

CONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVER-RIDE)

IPRINT  ITMAX   ICNDIR   NSCAL   ITRM   LINOBJ  NACMX1   NFDG
  5      20       5        0       3       0      10       0

 FDCH          FDCHM          CT             CTMIN
 0.10000E-01   0.10000E-02   -0.50000E-01    0.40000E-02

 CTL           CTLMIN         THETA          PHI
-0.10000E-01   0.10000E-02    0.10000E+01    0.0

 DELFUN        DABFUN         ALPHAX         ABOBJ1
 0.10000E-02   0.0            0.10000E+00    0.10000E+00

DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT
D. V.     LOWER          UPPER          INITIAL
NO.       BOUND          BOUND          VALUE          SCALE
 1     0.10000E+02    0.35000E+02    0.27000E+02    0.0
 2     0.50000E+01    0.25000E+02    0.16000E+02    0.0
 3     0.50000E+01    0.25000E+02    0.13000E+02    0.0
 4     0.50000E+01    0.25000E+02    0.90000E+01    0.0

DESIGN VARIABLES
      D. V.    GLOBAL     MULTIPLYING
ID    NO.     VAR. NO.      FACTOR
 1     1         1        0.10000E+01
```

```
   2     2        2      0.10000E+01
   3     3        3      0.10000E+01
   4     4        4      0.10000E+01
```

CONSTRAINT INFORMATION

THERE ARE 0 CONSTRAINT SETS

* * APPROXIMATE ANALYSIS/OPTIMIZATION INFORMATION

```
NUMBER OF FUNCTIONS APPROXIMATED, NF =     0
NUMBER OF INPUT X-VECTORS,       NPS =     5
NUMBER OF INPUT X-F PAIRS,      NPFS =     0
X-VECTOR FROM ANALIZ,            NPA =     0
NOMINAL DESIGN,                 INOM =     0
READ UNIT FOR X-VECTORS,       ISCRX =     5
READ UNIT FOR X-F PAIRS,      ISCRXF =     5
PRINT CONTROL,                IPAPRX =     1

MINIMUM APPROXIMATING CYCLES,   KMIN =     5
MAXIMUM APPROXIMATING CYCLES,   KMAX =    17
MAXIMUM DESIGNS USED IN FIT,   NFMAX =    28
NOMINAL DESIGN PARAMETER,       JNOM =    28
X-LOCATION INPUT PARAMETER,   INXLOC =     0
F-LOCATION INPUT PARAMETER,   INFLOC =     0
TAYLER SERIES I.D. CODE,      MAXTRM =     2

DELTA-X BOUNDS FOR APPROXIMATE OPTIMIZATION
0.2000E+01  0.2000E+01  0.2000E+01  0.2000E+01

MULTIPLIER ON DELX,           XFACT1 =  0.1500E+01
MULTIPLIER ON DELX,           XFACT2 =  0.2000E+01

GLOBAL LOCATIONS OF X-VARIABLES
    1    2    3    4

GLOBAL LOCATIONS OF FUNCTIONS
    7

X-VECTORS INPUT FROM UNIT    5

NUMBER    1     DESIGN    1
0.2900E+02  0.1800E+02  0.1500E+02  0.1100E+02

NUMBER    2     DESIGN    2
0.2700E+02  0.1800E+02  0.1500E+02  0.1100E+02

NUMBER    3     DESIGN    3
0.2700E+02  0.1600E+02  0.1500E+02  0.1100E+02
```

```
NUMBER    4      DESIGN    4
0.2700E+02  0.1600E+02  0.1300E+02  0.1100E+02

NUMBER    5      DESIGN    5
0.2700E+02  0.1600E+02  0.1300E+02  0.9000E+01

* * ESTIMATED DATA STORAGE REQUIREMENTS

          REAL                               INTEGER
INPUT  EXECUTION  AVAILABLE      INPUT  EXECUTION  AVAILABLE
  33      315       5000           22        64       1000
*********************************

SET VANE 1 TO   29.00 DEGREES

SET VANE 2 TO   18.00 DEGREES

SET VANE 3 TO   15.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
EFFICIENCY=     87.1400

*********************************

*********************************

SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   18.00 DEGREES

SET VANE 3 TO   15.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
EFFICIENCY=     87.3200
*********************************
```

```
SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   16.00 DEGREES

SET VANE 3 TO   15.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=      87.2400

*********************************

*********************************

SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   16.00 DEGREES

SET VANE 3 TO   13.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=      87.2000

*********************************

*********************************

SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   16.00 DEGREES

SET VANE 3 TO   13.00 DEGREES

SET VANE 4 TO    9.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500

HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=      87.3300

*********************************
```

```
APPROXIMATE OPTIMIZATION ITERATION HISTORY

APPROXIMATING FUNCTION    1     THE OBJECTIVE

DESIGN VARIABLE NUMBERS ASSOCIATED WITH APPROXIMATING VARIABLES
    1    2    3    4

BEGIN ITERATION NUMBER    1

NOMINAL DESIGN NUMBER =     5

X-VECTOR
  0.27000E+02  0.16000E+02  0.13000E+02  0.90000E+01

FUNCTION VALUES
  0.87330E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.20000E+01  0.20000E+01 -0.20000E+01 -0.20000E+01

X-VECTOR
  0.25000E+02  0.18000E+02  0.11000E+02  0.70000E+01

APPROXIMATE FUNCTION VALUES
  0.87680E+02
**********************************

SET VANE 1 TO   25.00 DEGREES

SET VANE 2 TO   18.00 DEGREES

SET VANE 3 TO   11.00 DEGREES

SET VANE 4 TO    7.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD OVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=     87.5200

**********************************

PRECISE FUNCTION VALUES
  0.87520E+02

BEGIN ITERATION NUMBER    2
```

```
NOMINAL DESIGN NUMBER =     6

X-VECTOR
  0.25000E+02  0.18000E+02  0.11000E+02  0.70000E+01

FUNCTION VALUES
  0.87520E+02


RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.75337E+00  0.20000E+01 -0.20000E+01 -0.20000E+01

X-VECTOR
  0.25753E+02  0.20000E+02  0.90000E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.87701E+02
********************************


SET VANE 1 TO   25.75 DEGREES


SET VANE 2 TO   20.00 DEGREES


SET VANE 3 TO    9.00 DEGREES


SET VANE 4 TO    5.00 DEGREES


HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
EFFICIENCY=     87.2800

********************************


PRECISE FUNCTION VALUES
  0.87280E+02


BEGIN ITERATION NUMBER     3

NOMINAL DESIGN NUMBER =     7

X-VECTOR
  0.25753E+02  0.20000E+02  0.90000E+01  0.50000E+01

FUNCTION VALUES
  0.87280E+02

RESULTS OF APPROXIMATE OPTIMIZATION
```

```
DELTA-X VECTOR
 -0.52557E-03 -0.10725E-04 -0.77730E-06 -0.97167E-06

X-VECTOR
  0.25753E+02  0.20000E+02  0.90000E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.87280E+02
*********************************

SET VANE 1 TO   25.75 DEGREES

SET VANE 2 TO   20.00 DEGREES

SET VANE 3 TO    9.00 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
EFFICIENCY=     87.2800

*********************************

PRECISE FUNCTION VALUES
  0.87280E+02

BEGIN ITERATION NUMBER     4

NOMINAL DESIGN NUMBER =     8

X-VECTOR
  0.25753E+02  0.20000E+02  0.90000E+01  0.50000E+01

FUNCTION VALUES
  0.87280E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.14439E+01 -0.23921E+01  0.30000E+01  0.0

X-VECTOR
  0.24309E+02  0.17608E+02  0.12000E+02  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.87600E+02
*********************************
```

```
SET VANE 1 TO   24.31 DEGREES

SET VANE 2 TO   17.61 DEGREES

SET VANE 3 TO   12.00 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=     87.4500

*********************************

PRECISE FUNCTION VALUES
  0.87450E+02

BEGIN ITERATION NUMBER    5

NOMINAL DESIGN NUMBER =    9

X-VECTOR
  0.24309E+02  0.17608E+02  0.12000E+02  0.50000E+01

FUNCTION VALUES
  0.87450E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.15768E+01 -0.25826E+00 -0.30000E+01  0.61882E+00

X-VECTOR
  0.25836E+02  0.17350E+02  0.90000E+01  0.56188E+01

APPROXIMATE FUNCTION VALUES
  0.87683E+02
*********************************

SET VANE 1 TO   25.89 DEGREES

SET VANE 2 TO   17.35 DEGREES

SET VANE 3 TO    9.00 DEGREES

SET VANE 4 TO    5.62 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=     87.3900

*********************************
```

```
PRECISE FUNCTION VALUES
  0.87390E+02


BEGIN ITERATION NUMBER    6

NOMINAL DESIGN NUMBER =   10

X-VECTOR
  0.25886E+02  0.17350E+02  0.90000E+01  0.56188E+01

FUNCTION VALUES
  0.87390E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.10000E+01  0.59866E+00  0.10000E+01  0.10000E+01

X-VECTOR
  0.24886E+02  0.17948E+02  0.10000E+02  0.66188E+01

APPROXIMATE FUNCTION VALUES
  0.87507E+02
********************************

SET VANE 1 TO   24.89 DEGREES

SET VANE 2 TO   17.95 DEGREES

SET VANE 3 TO   10.00 DEGREES

SET VANE 4 TO    6.62 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=     87.5000

********************************


PRECISE FUNCTION VALUES
```

```
   0.87500E+02

 BEGIN ITERATION NUMBER     7

 NOMINAL DESIGN NUMBER =    11

 X-VECTOR
   0.24886E+02  0.17948E+02  0.10000E+02  0.66188E+01

 FUNCTION VALUES
   0.87500E+02

 RESULTS OF APPROXIMATE OPTIMIZATION

 DELTA-X VECTOR
  -0.19008E+01  0.18232E-01  0.15271E+01  0.18999E+01

 X-VECTOR
   0.22986E+02  0.17966E+02  0.11527E+02  0.85188E+01

 APPROXIMATE FUNCTION VALUES
   0.87574E+02
******************************

 SET VANE 1 TO   22.99 DEGREES

 SET VANE 2 TO   17.97 DEGREES

 SET VANE 3 TO   11.53 DEGREES

 SET VANE 4 TO    8.52 DEGREES

 HOLD RFMC CONSTANT AT A VALUE OF       5567.500
 HOLD DVS  CONSTANT AT A VALUE OF         76.779
 EFFICIENCY=     87.3600
******************************

 PRECISE FUNCTION VALUES
   0.87360E+02

 BEGIN ITERATION NUMBER     8

 NOMINAL DESIGN NUMBER =    12

 X-VECTOR
   0.22986E+02  0.17966E+02  0.11527E+02  0.85188E+01
```

```
FUNCTION VALUES
  0.87360E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.26762E+01  0.27435E-01  0.74201E+00 -0.10959E+01

X-VECTOR
  0.25662E+02  0.17994E+02  0.12269E+02  0.74228E+01

APPROXIMATE FUNCTION VALUES
  0.87536E+02
**********************************

SET VANE 1 TO   25.66 DEGREES

SET VANE 2 TO   17.99 DEGREES

SET VANE 3 TO   12.27 DEGREES

SET VANE 4 TO    7.42 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=      87.5300

**********************************

PRECISE FUNCTION VALUES
  0.87530E+02

BEGIN ITERATION NUMBER     9

NOMINAL DESIGN NUMBER =    13

X-VECTOR
  0.25662E+02  0.17994E+02  0.12269E+02  0.74228E+01

FUNCTION VALUES
  0.87530E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.72962E-01 -0.20336E-03 -0.94522E-01  0.48190E-01

X-VECTOR
  0.25589E+02  0.17994E+02  0.12175E+02  0.74710E+01
```

```
APPROXIMATE FUNCTION VALUES
  0.87530E+02
********************************

SET VANE 1 TO   25.59 DEGREES

SET VANE 2 TO   17.99 DEGREES

SET VANE 3 TO   12.17 DEGREES

SET VANE 4 TO    7.47 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=     87.5300

********************************

PRECISE FUNCTION VALUES
  0.87530E+02

BEGIN ITERATION NUMBER   10

NOMINAL DESIGN NUMBER =   14

X-VECTOR
  0.25539E+02  0.17994E+02  0.12175E+02  0.74710E+01

FUNCTION VALUES
  0.87530E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.27530E-02 -0.53158E-03 -0.88454E-03  0.12517E-02

X-VECTOR
  0.25591E+02  0.17993E+02  0.12174E+02  0.74722E+01

APPROXIMATE FUNCTION VALUES
  0.87530E+02
********************************

SET VANE 1 TO   25.59 DEGREES

SET VANE 2 TO   17.99 DEGREES
```

```
SET VANE 3 TO   12.17 DEGREES

SET VANE 4 TO    7.47 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF        5567.500
HOLD DVS  CONSTANT AT A VALUE OF          76.779
EFFICIENCY=      87.5300

********************************

PRECISE FUNCTION VALUES
  0.87530E+02

FINAL RESULT OF APPROXIMATE OPTIMIZATION

NOMINAL DESIGN NUMBER =   15

X-VECTOR
  0.25591E+02  0.17993E+02  0.12174E+02  0.74722E+01

FUNCTION VALUES
  0.87530E+02

RESULTS OF APPROXIMATE ANALYSIS/OPTIMIZATION

TITLE
********************************************************

GLOBAL LOCATIONS OF X-VARIABLES
    1    2    3    4

GLOBAL LOCATIONS OF FUNCTIONS, F(X)
    7

APPROXIMATION IS BASED ON   15 DESIGNS

NOMINAL DESIGN IS DESIGN NUMBER   15

VALUES OF X-VARIABLES
   0.2559E+02   0.1799E+02   0.1217E+02   0.7472E+01

VALUES OF FUNCTIONS, F(X)
   0.8753E+02

COEFFICIENTS OF TAYLOR SERIES EXPANSION

PARAMETER    1 = GLOBAL VARIABLE    7

LINEAR TERMS, DEL F
   0.1770E-03  -0.2815E-04  -0.7172E-04   0.1071E-03

NON-LINEAR TERMS, H, BEGINING WITH DIAGONAL ELEMENT
```

```
ROW    1
  -0.4383E-01

ROW    2
  -0.6196E-01

ROW    3
  -0.1688E-01

ROW    4
  -0.1263E-01
```

OPTIMIZATION RESULTS

OBJECTIVE FUNCTION
GLOBAL LOCATION   7   *FUNCTION VALUE 0.87530E+02*

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	1	1	0.10000E+02	0.25591E+02	0.35000E+02
2	2	2	0.50000E+01	0.17993E+02	0.25000E+02
3	3	3	0.50000E+01	0.12174E+02	0.25000E+02
4	4	4	0.50000E+01	0.74722E+01	0.25000E+02

********* FINAL SOLUTION VALUES ********

VANE ANGLE FOR VANE 1 IS 25.59 DEGREES

VANE ANGLE FOR VANE 2 IS 17.99 DEGREES

VANE ANGLE FOR VANE 3 IS 12.17 DEGREES

VANE ANGLE FOR VANE 4 IS 7.47 DEGREES

EFFICIENCY= 87.5300

RPMC WAS HELD CONSTANT AT 5567.50
DVS WAS HELD CONSTANT AT 76.78

PROGRAM CALLS TO ANALIZ

ICALC	CALLS
1	1
2	15
3	1

STATOR VANE OPTIMIZER
****

PROTOTYPE SOFTWARE CAPABLE OF GUIDING THE OPTIMIZATION OF

STATOR VANE AND BLEED SETTINGS IN A MULTI-STAGE COMPRESSOR

PREPARED FOR THE AIR FORCE AERO PROPULSION LABORATORY

UNDER CONTRACT F33615-79-C-2013

BY: PRATT & WHITNEY AIRCRAFT GROUP
GOVERNMENT PRODUCTS DIVISION

PLEASE HIT RETURN TO VIEW OPTIMIZATION GOAL MENU

		OPTIMIZATION CONDITIONS					CONSTRAINTS	
NO	GOAL	RPMC	WC	FR	DVS	O.L.	S.M.	EFF
1	EFF	X	-	-	X	-	-	-
2	EFF	X	-	-	-	X	-	-
3	EFF	-	X	X	-	-	-	-
4	EFF	X	-	-	X	-	MIN	-
5	EFF	X	-	-	-	X	MIN	-
6	EFF	-	X	X	-	-	MIN	-
7	S.M.	X	-	-	X	-	-	-
8	S.M.	X	-	-	-	X	-	-
9	S.M.	-	X	X	-	-	-	-
10	S.M.	X	-	-	X	-	-	MIN
11	S.M.	X	-	-	-	X	-	MIN
12	S.M.	-	X	X	-	-	-	MIN
13	SM/BLD	X	X	-	-	-	-	-
14	MAX WC	X	-	-	-	X	MIN	MIN
15	MIN WC	X	-	-	-	X	MIN	MIN
16	FR	X	X	-	-	-	MIN	MIN
17	FR	X	-	-	-	X	MIN	MIN

YOU HAVE SELECTED TO OPTIMIZE EFFICIENCY HOLDING

CORRECTED SPEED (RPMC) AND DISCHARGE VALVE SETTING (DVS) CONSTANT

WITH NO CONSTRAINTS ON SURGE MARGIN
HOLD RPMC CONSTANT AT 5567.500
HOLD DVS CONSTANT AT 76.779
OPTIMIZING 4 VANE ANGLE(S)
LOWER BOUND FOR VANE 1 IS 10.000
DO YOU AGREE? (Y/N)
LOWER BOUND FOR VANE 2 IS 5.000
DO YOU AGREE? (Y/N)
LOWER BOUND FOR VANE 3 IS 5.000
DO YOU AGREE? (Y/N)
LOWER BOUND FOR VANE 4 IS 5.000
DO YOU AGREE? (Y/N)
UPPER BOUND FOR VANE 1 IS 35.000
DO YOU AGREE? (Y/N)
UPPER BOUND FOR VANE 2 IS 25.000
DO YOU AGREE? (Y/N)

UPPER BOUND FOR VANE 3 IS 25.000
DO YOU AGREE? (Y/N)
UPPER BOUND FOR VANE 4 IS 25.000
DO YOU AGREE? (Y/N)
INCREMENTAL VANE ANGLE VALUE FOR INITIAL VANE SETTING IS 2.00

```
TITLE:
*************************************************************

CONTROL PARAMETERS;
CALCULATION CONTROL,                         NCALC =    6
NUMBER OF GLOBAL DESIGN VARIABLES,           NDV =      4
NUMBER OF SENSITIVITY VARIABLES,             NSV =      0
NUMBER OF FUNCTIONS IN TWO-SPACE,          N2VAR =      0
NUMBER OF APPROXIMATING VAR.              NXAPRX =      4
INPUT INFORMATION PRINT CODE,             IFNPUT =      1
DEBUG PRINT CODE,                          IFDBG =      0

CALCULATION CONTROL, NCALC
VALUE   MEANING
  1     SINGLE ANALYSIS
  2     OPTIMIZATION
  3     SENSITIVITY
  4     TWO-VARIABLE FUNCTION SPACE
  5     OPTIMUM SENSITIVITY
  6     APPROXIMATE OPTIMIZATION

* * OPTIMIZATION INFORMATION

GLOBAL VARIABLE NUMBER OF OBJECTIVE               =    7
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION) =  0.1000E+01

CONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVER-RIDE)

IPRINT  ITMAX   ICNDIR   NSCAL   ITRM   LINOBJ  NACMX1   NFDG
   5      20       5       0       3       0      10       0

 FDCH            FDCHM           CT              CTMIN
 0.10000E-01     0.10000E-02     -0.50000E-01    0.40000E-02

 CTL             CTLMIN          THETA           PHI
-0.10000E-01     0.10000E-02     0.10000E+01     0.0

 DELFUN          DABFUN          ALPHAX          ABOBJ1
 0.10000E-02     0.0             0.10000E+00     0.10000E+00

DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT
D. V.      LOWER          UPPER          INITIAL
NO.        BOUND          BOUND          VALUE          SCALE
 1     0.10000E+02    0.35000E+02    0.20000E+02     0.0
 2     0.50000E+01    0.25000E+02    0.12000E+02     0.0
 3     0.50000E+01    0.25000E+02    0.70000E+01     0.0
 4     0.50000E+01    0.25000E+02    0.70000E+01     0.0

DESIGN VARIABLES
        D. V.     GLOBAL     MULTIPLYING
ID      NO.      VAR. NO.      FACTOR
 1       1          1        0.10000E+01

 2       2          2        0.10000E+01
 3       3          3        0.10000E+01
 4       4          4        0.10000E+01
```

```
CONSTRAINT INFORMATION

THERE ARE  0 CONSTRAINT SETS


* * APPROXIMATE ANALYSIS/OPTIMIZATION INFORMATION

NUMBER OF FUNCTIONS APPROXIMATED, NF  =     0
NUMBER OF INPUT X-VECTORS,        NPS  =     5
NUMBER OF INPUT X-F PAIRS,       NPFS  =     0
X-VECTOR FROM ANALIZ,             NPA  =     0
NOMINAL DESIGN,                  INOM  =     0
READ UNIT FOR X-VECTORS,        ISCRX  =     5
READ UNIT FOR X-F PAIRS,       ISCRXF  =     5
PRINT CONTROL,                 IPAPRX  =     1

MINIMUM APPROXIMATING CYCLES,    KMIN  =     5
MAXIMUM APPROXIMATING CYCLES,    KMAX  =    17
MAXIMUM DESIGNS USED IN FIT,    NFMAX  =    28
NOMINAL DESIGN PARAMETER,        JNOM  =    23
X-LOCATION INPUT PARAMETER,    INXLOC  =     0
F-LOCATION INPUT PARAMETER,    INFLOC  =     0
TAYLER SERIES I.D. CODE,       MAXTRM  =     2


DELTA-X BOUNDS FOR APPROXIMATE OPTIMIZATION
0.2000E+01  0.2000E+01  0.2000E+01  0.2000E+01

MULTIPLIER ON DELX,            XFACT1  =  0.1500E+01
MULTIPLIER ON DELX,            XFACT2  =  0.2000E+01


GLOBAL LOCATIONS OF X-VARIABLES
      1     2     3     4


GLOBAL LOCATIONS OF FUNCTIONS
      7


X-VECTORS INPUT FROM UNIT     5


NUMBER     1       DESIGN     1
0.1800E+02  0.1000E+02  0.5000E+01  0.5000E+01


NUMBER     2       DESIGN     2
0.2000E+02  0.1000E+02  0.5000E+01  0.5000E+01


NUMBER     3       DESIGN     3
0.2000E+02  0.1200E+02  0.5000E+01  0.5000E+01


NUMBER     4       DESIGN     4
0.2000E+02  0.1200E+02  0.7000E+01  0.5000E+01


NUMBER     5       DESIGN     5
0.2000E+02  0.1200E+02  0.7000E+01  0.7000E+01
```

```
* * ESTIMATED DATA STORAGE REQUIREMENTS

            REAL                                   INTEGER
  INPUT  EXECUTION  AVAILABLE          INPUT  EXECUTION  AVAILABLE
    33      315       5000               22       64        1000
********************************

SET VANE 1 TO   18.00 DEGREES

SET VANE 2 TO   10.00 DEGREES

SET VANE 3 TO    5.00 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
EFFICIENCY=      86.6000

********************************

********************************

SET VANE 1 TO   20.00 DEGREES

SET VANE 2 TO   10.00 DEGREES

SET VANE 3 TO    5.00 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
EFFICIENCY=      86.7400

********************************

********************************

SET VANE 1 TO   20.00 DEGREES

SET VANE 2 TO   12.00 DEGREES

SET VANE 3 TO    5.00 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
EFFICIENCY=      86.9000

********************************

********************************

SET VANE 1 TO   20.00 DEGREES

SET VANE 2 TO   12.00 DEGREES

SET VANE 3 TO    7.00 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
EFFICIENCY=      86.9800
```

```
SET VANE 1 TO   20.00 DEGREES

SET VANE 2 TO   12.00 DEGREES

SET VANE 3 TO    7.00 DEGREES

SET VANE 4 TO    7.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
EFFICIENCY=     87.0200

********************************
APPROXIMATE OPTIMIZATION ITERATION HISTORY

APPROXIMATING FUNCTION    1 IS THE OBJECTIVE

DESIGN VARIABLE NUMBERS ASSOCIATED WITH APPROXIMATING VARIABLES
    1    2    3    4

BEGIN ITERATION NUMBER    1

NOMINAL DESIGN NUMBER =    5

X-VECTOR
  0.20000E+02  0.12000E+02  0.70000E+01  0.70000E+01

FUNCTION VALUES
  0.87020E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.20000E+01  0.20000E+01  0.20000E+01  0.20000E+01

X-VECTOR
  0.22000E+02  0.14000E+02  0.90000E+01  0.90000E+01

APPROXIMATE FUNCTION VALUES
  0.87440E+02
********************************

SET VANE 1 TO   22.00 DEGREES

SET VANE 2 TO   14.00 DEGREES

SET VANE 3 TO    9.00 DEGREES

SET VANE 4 TO    9.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=     87.2000

********************************

PRECISE FUNCTION VALUES
  0.87200E+02

BEGIN ITERATION NUMBER    2

NOMINAL DESIGN NUMBER =    6

X-VECTOR
```

```
0.22000E+02  0.14000E+02  0.90000E+01  0.90000E+01

FUNCTION VALUES
 0.87200E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
-0.17195E+01  0.20000E+01  0.20000E+01  0.20000E+01

X-VECTOR
 0.20281E+02  0.16000E+02  0.11000E+02  0.11000E+02

APPROXIMATE FUNCTION VALUES
 0.87580E+02
********************************

SET VANE 1 TO   20.28 DEGREES

SET VANE 2 TO   16.00 DEGREES

SET VANE 3 TO   11.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
EFFICIENCY=      87.0600

********************************

PRECISE FUNCTION VALUES
 0.87060E+02

BEGIN ITERATION NUMBER     3

NOMINAL DESIGN NUMBER =     7

X-VECTOR
 0.20281E+02  0.16000E+02  0.11000E+02  0.11000E+02

FUNCTION VALUES
 0.87060E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 0.30000E+01 -0.30000E+01  0.20000E+01  0.20000E+01

X-VECTOR
 0.23281E+02  0.13000E+02  0.13000E+02  0.13000E+02

APPROXIMATE FUNCTION VALUES
```

```
    0.87489E+02
  ********************************

    SET VANE 1 TO    23.28 DEGREES

    SET VANE 2 TO    13.00 DEGREES

    SET VANE 3 TO    13.00 DEGREES

    SET VANE 4 TO    13.00 DEGREES

    HOLD RPMC CONSTANT AT A VALUE OF       5567.500
    HOLD DVS  CONSTANT AT A VALUE OF         76.779
    EFFICIENCY=      86.8100

  ********************************


    PRECISE FUNCTION VALUES
      0.86810E+02


    BEGIN ITERATION NUMBER     4

    NOMINAL DESIGN NUMBER =    8

    X-VECTOR
      0.23281E+02  0.13000E+02  0.13000E+02  0.13000E+02

    FUNCTION VALUES
      0.86810E+02


    RESULTS OF APPROXIMATE OPTIMIZATION

    DELTA-X VECTOR
      0.25161E+00  0.30000E+01 -0.30000E+01  0.20000E+01

    X-VECTOR
      0.23532E+02  0.16000E+02  0.10000E+02  0.15000E+02

    APPROXIMATE FUNCTION VALUES
      0.87317E+02
  ********************************

    SET VANE 1 TO    23.53 DEGREES

    SET VANE 2 TO    16.00 DEGREES

    SET VANE 3 TO    10.00 DEGREES

    SET VANE 4 TO    15.00 DEGREES

    HOLD RPMC CONSTANT AT A VALUE OF       5567.500
    HOLD DVS  CONSTANT AT A VALUE OF         76.779
    EFFICIENCY=      86.5400
```

PRECISE FUNCTION VALUES
0.86540E+02

BEGIN ITERATION NUMBER 5

NOMINAL DESIGN NUMBER = 9

X-VECTOR
0.23532E+02 0.16000E+02 0.10000E+02 0.15000E+02

FUNCTION VALUES
0.86540E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
0.20387E-01 0.58720E+00 0.23484E+01 -0.30000E+01

X-VECTOR
0.23552E+02 0.16587E+02 0.12348E+02 0.12000E+02

APPROXIMATE FUNCTION VALUES
0.87039E+02
****

SET VANE 1 TO 23.55 DEGREES

SET VANE 2 TO 16.59 DEGREES

SET VANE 3 TO 12.35 DEGREES

SET VANE 4 TO 12.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF 5567.500
HOLD DVS CONSTANT AT A VALUE OF 76.779
EFFICIENCY= 87.1300

****

PRECISE FUNCTION VALUES
0.87180E+02

BEGIN ITERATION NUMBER 6

NOMINAL DESIGN NUMBER = 10

X-VECTOR

0.23552E+02 0.16587E+02 0.12348E+02 0.12000E+02

FUNCTION VALUES
0.87180E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
0.30000E+01 0.30000E+01 0.30000E+01 -0.30000E+01

X-VECTOR
0.26552E+02 0.19587E+02 0.15348E+02 0.90000E+01

APPROXIMATE FUNCTION VALUES
0.87813E+02
****

```
SET VANE 1 TO   26.55 DEGREES

SET VANE 2 TO   19.59 DEGREES

SET VANE 3 TO   15.35 DEGREES

SET VANE 4 TO    9.00 DEGREES

HOLD RFMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=     87.3200

*********************************


PRECISE FUNCTION VALUES
  0.87320E+02


BEGIN ITERATION NUMBER     7

NOMINAL DESIGN NUMBER =    11

X-VECTOR
  0.26552E+02  0.19587E+02  0.15348E+02  0.90000E+01

FUNCTION VALUES
  0.87320E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.30000E+01 -0.37551E+00 -0.57363E+00 -0.22680E+01

X-VECTOR
  0.23552E+02  0.19212E+02  0.14775E+02  0.67320E+01

APPROXIMATE FUNCTION VALUES

  0.87493E+02
*********************************

SET VANE 1 TO   23.55 DEGREES

SET VANE 2 TO   19.21 DEGREES

SET VANE 3 TO   14.77 DEGREES

SET VANE 4 TO    6.73 DEGREES

HOLD RFMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=     87.2700

*********************************


PRECISE FUNCTION VALUES
  0.87270E+02
```

```
BEGIN ITERATION NUMBER     8

NOMINAL DESIGN NUMBER =    12

X-VECTOR
  0.23552E+02  0.19212E+02  0.14775E+02  0.67320E+01

FUNCTION VALUES
  0.87270E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.10000E+01 -0.10000E+01 -0.10000E+01  0.69491E+00

X-VECTOR
  0.24552E+02  0.18212E+02  0.13775E+02  0.74269E+01

APPROXIMATE FUNCTION VALUES
  0.87332E+02
*********************************

SET VANE 1 TO   24.55 DEGREES

SET VANE 2 TO   18.21 DEGREES

SET VANE 3 TO   13.77 DEGREES

SET VANE 4 TO    7.43 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=     87.4700

PRECISE FUNCTION VALUES
  0.87470E+02

BEGIN ITERATION NUMBER     9

NOMINAL DESIGN NUMBER =    13

X-VECTOR
  0.24552E+02  0.18212E+02  0.13775E+02  0.74269E+01

FUNCTION VALUES
  0.87470E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.30000E+01 -0.22538E+01 -0.27219E+01 -0.11338E+01

X-VECTOR
  0.27552E+02  0.15958E+02  0.11053E+02  0.62931E+01

APPROXIMATE FUNCTION VALUES
  0.87775E+02
*********************************

SET VANE 1 TO   27.55 DEGREES

SET VANE 2 TO   15.96 DEGREES
```

SET VANE 3 TO 11.05 DEGREES

SET VANE 4 TO 6.29 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF 5567.500
HOLD DVS CONSTANT AT A VALUE OF 76.779
EFFICIENCY= 87.2300

****

PRECISE FUNCTION VALUES
0.87230E+02

BEGIN ITERATION NUMBER 10

NOMINAL DESIGN NUMBER = 14

X-VECTOR

0.27552E+02 0.15958E+02 0.11053E+02 0.62931E+01

FUNCTION VALUES
0.87230E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
-0.30000E+01 0.18264E+01 0.62902E+00 0.14670E+01

X-VECTOR
0.24552E+02 0.17784E+02 0.11682E+02 0.77601E+01

APPROXIMATE FUNCTION VALUES
0.87384E+02
****

SET VANE 1 TO 24.55 DEGREES

SET VANE 2 TO 17.78 DEGREES

SET VANE 3 TO 11.68 DEGREES

SET VANE 4 TO 7.76 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF 5567.500
HOLD DVS CONSTANT AT A VALUE OF 76.779
EFFICIENCY= 87.5200

****

PRECISE FUNCTION VALUES
0.87520E+02

BEGIN ITERATION NUMBER 11

NOMINAL DESIGN NUMBER = 15

X-VECTOR
0.24552E+02 0.17784E+02 0.11682E+02 0.77601E+01

FUNCTION VALUES
0.87520E+02

```
RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.15094E+00  0.30000E+01 -0.27914E+01  0.12013E+00

X-VECTOR
  0.24402E+02  0.20784E+02  0.88905E+01  0.78802E+01

APPROXIMATE FUNCTION VALUES

  0.87778E+02
*********************************

SET VANE 1 TO   24.40 DEGREES

SET VANE 2 TO   20.78 DEGREES

SET VANE 3 TO    8.89 DEGREES

SET VANE 4 TO    7.88 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=     87.3000

*********************************


PRECISE FUNCTION VALUES
  0.87300E+02


BEGIN ITERATION NUMBER   12

NOMINAL DESIGN NUMBER =   16

X-VECTOR
  0.24402E+02  0.20784E+02  0.88905E+01  0.78802E+01

FUNCTION VALUES
  0.87300E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.12274E+00 -0.30000E+01  0.13476E+01 -0.12194E+00

X-VECTOR
  0.24279E+02  0.17784E+02  0.10238E+02  0.77583E+01

APPROXIMATE FUNCTION VALUES
  0.87408E+02
*********************************

SET VANE 1 TO   24.28 DEGREES

SET VANE 2 TO   17.78 DEGREES

SET VANE 3 TO   10.24 DEGREES

SET VANE 4 TO    7.76 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=     87.4900
```

```
PRECISE FUNCTION VALUES
  0.87490E+02

BEGIN ITERATION NUMBER   13

NOMINAL DESIGN NUMBER =   17

X-VECTOR
  0.24279E+02  0.17784E+02  0.10238E+02  0.77583E+01

FUNCTION VALUES
  0.87490E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.13056E-01 -0.74511E+00 -0.18030E+01 -0.28726E+00

X-VECTOR
  0.24266E+02  0.17039E+02  0.84351E+01  0.74710E+01

APPROXIMATE FUNCTION VALUES
  0.87526E+02
********************************

SET VANE 1 TO   24.27 DEGREES

SET VANE 2 TO   17.04 DEGREES

SET VANE 3 TO    8.44 DEGREES

SET VANE 4 TO    7.47 DEGREES

HOLD PRMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=    87.4900

********************************

PRECISE FUNCTION VALUES
  0.87490E+02

BEGIN ITERATION NUMBER   14

NOMINAL DESIGN NUMBER =   18

X-VECTOR

  0.24266E+02  0.17039E+02  0.84351E+01  0.74710E+01

FUNCTION VALUES
  0.87490E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.13986E+00  0.15656E-01 -0.10000E+01  0.26333E+00

X-VECTOR
  0.24406E+02  0.17055E+02  0.74351E+01  0.77344E+01

APPROXIMATE FUNCTION VALUES
  0.87508E+02
********************************
```

```
SET VANE 1 TO   24.41 DEGREES

SET VANE 2 TO   17.05 DEGREES

SET VANE 3 TO    7.44 DEGREES

SET VANE 4 TO    7.73 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
EFFICIENCY=     87.4300

********************************

PRECISE FUNCTION VALUES
  0.87430E+02

FINAL RESULT OF APPROXIMATE OPTIMIZATION

NOMINAL DESIGN NUMBER =   15

X-VECTOR
  0.24552E+02  0.17784E+02  0.11652E+02  0.77601E+01

FUNCTION VALUES
  0.87520E+02

RESULTS OF APPROXIMATE ANALYSIS/OPTIMIZATION

TITLE
****************************************************************

GLOBAL LOCATIONS OF X-VARIABLES
    1    2    3    4

GLOBAL LOCATIONS OF FUNCTIONS, F(X)
    7

APPROXIMATION IS BASED ON   19 DESIGNS

NOMINAL DESIGN IS DESIGN NUMBER   15

VALUES OF X-VARIABLES
   0.2455E+02   0.1778E+02   0.1168E+02   0.7760E+01

VALUES OF FUNCTIONS, F(X)
   0.8752E+02

COEFFICIENTS OF TAYLOR SERIES EXPANSION

PARAMETER    1 = GLOBAL VARIABLE    7

LINEAR TERMS, DEL F
  -0.1274E-01  -0.1145E-01  -0.3592E-02  -0.2156E-01

NON-LINEAR TERMS, H, BEGINING WITH DIAGONAL ELEMENT
```

ROW 1
-0.2531E-01

ROW 2
-0.1401E-01

ROW 3
-0.9645E-02

ROW 4
-0.3166E-01

OPTIMIZATION RESULTS

OBJECTIVE FUNCTION
GLOBAL LOCATION 7 FUNCTION VALUE 0.87520E+02

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	1	1	0.10000E+02	0.24552E+02	0.35000E+02
2	2	2	0.50000E+01	0.17784E+02	0.25000E+02
3	3	3	0.50000E+01	0.11682E+02	0.25000E+02
4	4	4	0.50000E+01	0.77601E+01	0.25000E+02

********* FINAL SOLUTION VALUES ********

VANE ANGLE FOR VANE 1 IS 24.55 DEGREES

VANE ANGLE FOR VANE 2 IS 17.78 DEGREES

VANE ANGLE FOR VANE 3 IS 11.68 DEGREES

VANE ANGLE FOR VANE 4 IS 7.76 DEGREES

EFFICIENCY= 87.5200

RPMC WAS HELD CONSTANT AT 5567.50
DVS WAS HELD CONSTANT AT 76.78

PROGRAM CALLS TO ANALIZ

ICALC	CALLS
1	1
2	19
3	1

STATOR VANE OPTIMIZER

****

PROTOTYPE SOFTWARE CAPABLE OF GUIDING THE OPTIMIZATION OF

STATOR VANE AND BLEED SETTINGS IN A MULTI-STAGE COMPRESSOR

PREPARED FOR THE AIR FORCE AERO PROPULSION LABORATORY

UNDER CONTRACT F33615-79-C-2013

BY: PRATT & WHITNEY AIRCRAFT GROUP
GOVERNMENT PRODUCTS DIVISION

PLEASE HIT RETURN TO VIEW OPTIMIZATION GOAL MENU

NO	GOAL	OPTIMIZATION CONDITIONS RPMC	WC	PR	DVS	O.L.	CONSTRAINTS S.M.	EFF
1	EFF	X	-	-	X	-	-	-
2	EFF	X	-	-	-	X	-	-
3	EFF	-	X	X	-	-	-	-
4	EFF	X	-	-	X	-	MIN	-
5	EFF	X	-	-	-	X	MIN	-
6	EFF	-	X	X	-	-	MIN	-
7	S.M.	X	-	-	X	-	-	-
8	S.M.	X	-	-	-	X	-	-
9	S.M.	-	X	X	-	-	-	-
10	S.M.	X	-	-	X	-	-	MIN
11	S.M.	X	-	-	-	X	-	MIN
12	S.M.	-	X	X	-	-	-	MIN
13	SM/BLD	X	X	-	-	-	-	-
14	MAX WC	X	-	-	-	X	MIN	MIN
15	MIN WC	X	-	-	-	X	MIN	MIN
16	PR	X	X	-	-	-	MIN	MIN
17	PR	X	-	-	-	X	MIN	MIN

YOU HAVE SELECTED TO OPTIMIZE SURGE MARGIN HOLDING

CORRECTED SPEED (RPMC) AND DISCHARGE VALVE SETTING (DVS) CONSTANT

WITH NO CONSTRAINT ON EFFICIENCY
HOLD RPMC CONSTANT AT 5567.500
HOLD DVS CONSTANT AT 76.779
OPTIMIZING 4 VANE ANGLE(S)
LOWER BOUND FOR VANE 1 IS 10.000
DO YOU AGREE? (Y/N)
LOWER BOUND FOR VANE 2 IS 5.000
DO YOU AGREE? (Y/N)
LOWER BOUND FOR VANE 3 IS 5.000
DO YOU AGREE? (Y/N)
LOWER BOUND FOR VANE 4 IS 5.000
DO YOU AGREE? (Y/N)
UPPER BOUND FOR VANE 1 IS 35.000
DO YOU AGREE? (Y/N)
UPPER BOUND FOR VANE 2 IS 25.000
DO YOU AGREE? (Y/N)

UPPER BOUND FOR VANE 3 IS 25.000
DO YOU AGREE? (Y/N)
UPPER BOUND FOR VANE 4 IS 25.000
DO YOU AGREE? (Y/N)
INCREMENTAL VANE ANGLE VALUE FOR INITIAL VANE SETTING IS -2.00

```
TITLE:
************************************************************

CONTROL PARAMETERS;
CALCULATION CONTROL,                        NCALC =    6
NUMBER OF GLOBAL DESIGN VARIABLES,            NDV =    4
NUMBER OF SENSITIVITY VARIABLES,              NSV =    0
NUMBER OF FUNCTIONS IN TWO-SPACE,           N2VAR =    0
NUMBER OF APPROXIMATING VAR.               NXAPRX =    4
INPUT INFORMATION PRINT CODE,              IPNPUT =    1
DEBUG PRINT CODE,                           IPDBG =    0

CALCULATION CONTROL, NCALC
VALUE   MEANING
  1     SINGLE ANALYSIS
  2     OPTIMIZATION
  3     SENSITIVITY
  4     TWO-VARIABLE FUNCTION SPACE
  5     OPTIMUM SENSITIVITY
  6     APPROXIMATE OPTIMIZATION

* * OPTIMIZATION INFORMATION

GLOBAL VARIABLE NUMBER OF OBJECTIVE          =    6
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION) =  0.1000E+01

CONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVER-RIDE)

IPRINT  ITMAX   ICNDIR   NSCAL   ITRM   LINOBJ  NACMX1   NFDG
  5      20       5        0       3       0      10       0

 FDCH            FDCHM           CT              CTMIN
 0.10000E-01     0.10000E-02     -0.50000E-01    0.40000E-02

CTL             CTLMIN          THETA           PHI
-0.10000E-01     0.10000E-02     0.10000E+01    0.0

 DELFUN          DABFUN          ALPHAX          ABOBJ1
 0.10000E-02     0.0             0.10000E+00     0.10000E+00

DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT
D. V.      LOWER          UPPER          INITIAL
NO.        BOUND          BOUND          VALUE          SCALE
  1     0.10000E+02    0.35000E+02    0.27000E+02     0.0
  2     0.50000E+01    0.25000E+02    0.16000E+02     0.0
  3     0.50000E+01    0.25000E+02    0.13000E+02     0.0
  4     0.50000E+01    0.25000E+02    0.90000E+01     0.0

DESIGN VARIABLES
        D. V.    GLOBAL    MULTIPLYING
ID      NO.     VAR. NO.     FACTOR
 1       1         1       0.10000E+01

 2       2         2       0.10000E+01
 3       3         3       0.10000E+01
 4       4         4       0.10000E+01

CONSTRAINT INFORMATION

THERE ARE  0 CONSTRAINT SETS
```

```
*.*_APPROXIMATE ANALYSIS/OPTIMIZATION INFORMATION

NUMBER OF FUNCTIONS APPROXIMATED, NF =     0
NUMBER OF INPUT X-VECTORS,       NPS =     5
NUMBER OF INPUT X-F PAIRS,      NPFS =     0
X-VECTOR FROM ANALIZ,            NPA =     0
NOMINAL DESIGN,                 INOM =     0
READ UNIT FOR X-VECTORS,       ISCRX =     5
READ UNIT FOR X-F PAIRS,      ISCRXF =     5
PRINT CONTROL,                IPAPRX =     1

MINIMUM APPROXIMATING CYCLES,   KMIN =     5
MAXIMUM APPROXIMATING CYCLES,   KMAX =    17
MAXIMUM DESIGNS USED IN FIT,   NPMAX =    28
NOMINAL DESIGN PARAMETER,       JNOM =    28
X-LOCATION INPUT PARAMETER,   INXLOC =     0
F-LOCATION INPUT PARAMETER,   INFLOC =     0
TAYLER SERIES I.D. CODE,      MAXTRM =     2

DELTA-X BOUNDS FOR APPROXIMATE OPTIMIZATION
0.2000E+01  0.2000E+01  0.2000E+01  0.2000E+01

MULTIPLIER ON DELX,           XFACT1 =  0.1500E+01
MULTIPLIER ON DELX,           XFACT2 =  0.2000E+01

GLOBAL LOCATIONS OF X-VARIABLES
     1    2    3    4

GLOBAL LOCATIONS OF FUNCTIONS
     6

X-VECTORS INPUT FROM UNIT     5

NUMBER    1     DESIGN    1
0.2900E+02  0.1800E+02  0.1500E+02  0.1100E+02

NUMBER    2     DESIGN    2
0.2700E+02  0.1800E+02  0.1500E+02  0.1100E+02

NUMBER    3     DESIGN    3
0.2700E+02  0.1600E+02  0.1500E+02  0.1100E+02

NUMBER    4     DESIGN    4
0.2700E+02  0.1600E+02  0.1300E+02  0.1100E+02

NUMBER    5     DESIGN    5
0.2700E+02  0.1600E+02  0.1300E+02  0.9000E+01

*.* ESTIMATED DATA STORAGE REQUIREMENTS

          REAL                              INTEGER
INPUT  EXECUTION  AVAILABLE     INPUT  EXECUTION  AVAILABLE
  33      315       5000          22       64        1000
*************************************
```

```
SET VANE 1 TO   29.00 DEGREES

SET VANE 2 TO   18.00 DEGREES

SET VANE 3 TO   15.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
SURGE MARGIN=    8.2600

********************************

********************************

SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   18.00 DEGREES

SET VANE 3 TO   15.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
SURGE MARGIN=    8.7500

********************************

********************************

SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   16.00 DEGREES

SET VANE 3 TO   15.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
SURGE MARGIN=    8.8700

********************************

********************************

SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   16.00 DEGREES

SET VANE 3 TO   13.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
SURGE MARGIN=    9.1200
```

```
SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   16.00 DEGREES

SET VANE 3 TO   13.00 DEGREES

SET VANE 4 TO    9.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
SURGE MARGIN=     9.1800

APPROXIMATE OPTIMIZATION ITERATION HISTORY

APPROXIMATING FUNCTION     1 IS THE OBJECTIVE

DESIGN VARIABLE NUMBERS ASSOCIATED WITH APPROXIMATING VARIABLES
    1    2    3    4

BEGIN ITERATION NUMBER     1

NOMINAL DESIGN NUMBER =     5

X-VECTOR
  0.27000E+02  0.16000E+02  0.13000E+02  0.90000E+01

FUNCTION VALUES
  0.91800E+01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.20000E+01 -0.20000E+01 -0.20000E+01 -0.20000E+01

X-VECTOR
  0.25000E+02  0.14000E+02  0.11000E+02  0.70000E+01

APPROXIMATE FUNCTION VALUES
  0.10100E+02
********************************

SET VANE 1 TO   25.00 DEGREES

SET VANE 2 TO   14.00 DEGREES

SET VANE 3 TO   11.00 DEGREES

SET VANE 4 TO    7.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
SURGE MARGIN=     9.6300

********************************

PRECISE FUNCTION VALUES
  0.96300E+01

BEGIN ITERATION NUMBER     2

NOMINAL DESIGN NUMBER =     6

X-VECTOR
```

```
   0.25000E+02  0.14000E+02  0.11000E+02  0.70000E+01

 FUNCTION VALUES
   0.96300E+01

 RESULTS OF APPROXIMATE OPTIMIZATION

 DELTA-X VECTOR
   0.91473E+00 -0.20000E+01 -0.20000E+01 -0.20000E+01

 X-VECTOR
   0.25915E+02  0.12000E+02  0.90000E+01  0.50000E+01

 APPROXIMATE FUNCTION VALUES
   0.10109E+02
********************************


 SET VANE 1 TO   25.91 DEGREES

 SET VANE 2 TO   12.00 DEGREES

 SET VANE 3 TO    9.00 DEGREES

 SET VANE 4 TO    5.00 DEGREES

 HOLD RPMC CONSTANT AT A VALUE OF      5567.500
 HOLD DVS  CONSTANT AT A VALUE OF        76.779
 SURGE MARGIN=     9.6500

********************************


 PRECISE FUNCTION VALUES
   0.96500E+01


 BEGIN ITERATION NUMBER     3

 NOMINAL DESIGN NUMBER =     7

 X-VECTOR
   0.25915E+02  0.12000E+02  0.90000E+01  0.50000E+01

 FUNCTION VALUES
   0.96500E+01

 RESULTS OF APPROXIMATE OPTIMIZATION

 DELTA-X VECTOR
  -0.12697E+01  0.30000E+01 -0.20000E+01 -0.19073E-05

 X-VECTOR
   0.24645E+02  0.15000E+02  0.70000E+01  0.50000E+01

 APPROXIMATE FUNCTION VALUES
```

```
  0.10246E+02
********************************

  SET VANE 1 TO   24.65 DEGREES

  SET VANE 2 TO   15.00 DEGREES

  SET VANE 3 TO    7.00 DEGREES

  SET VANE 4 TO    5.00 DEGREES

  HOLD RPMC CONSTANT AT A VALUE OF       5567.500
  HOLD DVS  CONSTANT AT A VALUE OF         76.779
  SURGE MARGIN=    9.8100
********************************

  PRECISE FUNCTION VALUES
    0.98100E+01

  BEGIN ITERATION NUMBER    4

  NOMINAL DESIGN NUMBER =    8

  X-VECTOR
    0.24645E+02  0.15000E+02  0.70000E+01  0.50000E+01

  FUNCTION VALUES
    0.98100E+01

  RESULTS OF APPROXIMATE OPTIMIZATION

  DELTA-X VECTOR
   -0.53915E-03 -0.38695E+00  0.54003E+00  0.10737E-06

  X-VECTOR
    0.24644E+02  0.14613E+02  0.75400E+01  0.50000E+01

  APPROXIMATE FUNCTION VALUES
    0.98143E+01
********************************

  SET VANE 1 TO   24.64 DEGREES

  SET VANE 2 TO   14.61 DEGREES

  SET VANE 3 TO    7.54 DEGREES

  SET VANE 4 TO    5.00 DEGREES

  HOLD RPMC CONSTANT AT A VALUE OF       5567.500
  HOLD DVS  CONSTANT AT A VALUE OF         76.779
  SURGE MARGIN=    9.7300
```

```
PRECISE FUNCTION VALUES
  0.97300E+01

BEGIN ITERATION NUMBER    5

NOMINAL DESIGN NUMBER =    9

X-VECTOR
  0.24644E+02  0.14613E+02  0.75400E+01  0.50000E+01

FUNCTION VALUES
  0.97300E+01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.10392E-02 -0.30000E+01 -0.25400E+01  0.30000E+01

X-VECTOR
  0.24645E+02  0.11613E+02  0.50000E+01  0.80000E+01

APPROXIMATE FUNCTION VALUES
  0.11230E+02
********************************

SET VANE 1 TO   24.65 DEGREES

SET VANE 2 TO   11.61 DEGREES

SET VANE 3 TO    5.00 DEGREES

SET VANE 4 TO    8.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
SURGE MARGIN=    9.8600

********************************

PRECISE FUNCTION VALUES
  0.98600E+01

BEGIN ITERATION NUMBER    6

NOMINAL DESIGN NUMBER =   10

X-VECTOR

  0.24645E+02  0.11613E+02  0.50000E+01  0.80000E+01

FUNCTION VALUES
  0.98600E+01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.17830E+00  0.16957E+01  0.0          -0.21006E+00

X-VECTOR
  0.24824E+02  0.13309E+02  0.50000E+01  0.77899E+01

APPROXIMATE FUNCTION VALUES
  0.98910E+01
```

```
*********************************

SET VANE 1 TO   24.82 DEGREES

SET VANE 2 TO   13.31 DEGREES

SET VANE 3 TO    5.00 DEGREES

SET VANE 4 TO    7.79 DEGREES

HOLD RFMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
SURGE MARGIN=    9.7100

*********************************


PRECISE FUNCTION VALUES
  0.97100E+01


BEGIN ITERATION NUMBER    7

NOMINAL DESIGN NUMBER =   11

X-VECTOR
  0.24824E+02  0.13309E+02  0.50000E+01  0.77899E+01

FUNCTION VALUES
  0.97100E+01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.25804E+01 -0.30000E+01  0.30000E+01  0.17808E+01

X-VECTOR
  0.22243E+02  0.10309E+02  0.80000E+01  0.95708E+01

APPROXIMATE FUNCTION VALUES


  0.10101E+02
*********************************

SET VANE 1 TO   22.24 DEGREES

SET VANE 2 TO   10.31 DEGREES

SET VANE 3 TO    8.00 DEGREES

SET VANE 4 TO    9.57 DEGREES

HOLD RFMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
SURGE MARGIN=    9.9000

*********************************


PRECISE FUNCTION VALUES
  0.99000E+01
```

BEGIN ITERATION NUMBER 8

NOMINAL DESIGN NUMBER = 12

X-VECTOR
0.22243E+02 0.10309E+02 0.80000E+01 0.95708E+01

FUNCTION VALUES
0.99000E+01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
0.11631E+01 -0.30000E+01 -0.59621E+00 -0.80193E+00

X-VECTOR
0.23407E+02 0.73088E+01 0.74038E+01 0.87689E+01

APPROXIMATE FUNCTION VALUES
0.99636E+01
****

SET VANE 1 TO 23.41 DEGREES

SET VANE 2 TO 7.31 DEGREES

SET VANE 3 TO 7.40 DEGREES

SET VANE 4 TO 8.77 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF 5567.500
HOLD DVS CONSTANT AT A VALUE OF 76.779
SURGE MARGIN= 9.8500

PRECISE FUNCTION VALUES
0.98500E+01

BEGIN ITERATION NUMBER 9

NOMINAL DESIGN NUMBER = 13

X-VECTOR
0.23407E+02 0.73088E+01 0.74038E+01 0.87689E+01

FUNCTION VALUES
0.98500E+01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
-0.29393E+00 0.30000E+01 -0.74344E-01 0.21588E+00

X-VECTOR
0.23113E+02 0.10309E+02 0.73294E+01 0.89847E+01

APPROXIMATE FUNCTION VALUES
0.99191E+01
****

SET VANE 1 TO 23.11 DEGREES

SET VANE 2 TO 10.31 DEGREES

SET VANE 3 TO 7.33 DEGREES

SET VANE 4 TO 8.98 DEGREES

```
HOLD RPMC CONSTANT AT A VALUE OF        5567.500
HOLD DVS  CONSTANT AT A VALUE OF          76.779
SURGE MARGIN=     9.9000

**********************************

PRECISE FUNCTION VALUES
   0.99000E+01

BEGIN ITERATION NUMBER    10

NOMINAL DESIGN NUMBER =    14

X-VECTOR

   0.23113E+02  0.10309E+02  0.73294E+01  0.89847E+01

FUNCTION VALUES
   0.99000E+01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
   0.99483E-01  0.64460E+00 -0.39840E-01 -0.61202E+00

X-VECTOR
   0.23212E+02  0.10953E+02  0.72896E+01  0.83727E+01

APPROXIMATE FUNCTION VALUES
   0.99032E+01
**********************************

SET VANE 1 TO    23.21 DEGREES

SET VANE 2 TO    10.95 DEGREES

SET VANE 3 TO     7.29 DEGREES

SET VANE 4 TO     8.37 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF        5567.500
HOLD DVS  CONSTANT AT A VALUE OF          76.779
SURGE MARGIN=     9.6500

**********************************

PRECISE FUNCTION VALUES
   0.96500E+01

BEGIN ITERATION NUMBER    11

NOMINAL DESIGN NUMBER =    15

X-VECTOR
   0.23212E+02  0.10953E+02  0.72896E+01  0.83727E+01

FUNCTION VALUES
   0.96500E+01
```

```
RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.47319E+00 -0.14892E+01 -0.22697E+00  0.30000E+01

X-VECTOR
  0.23685E+02  0.94642E+01  0.70626E+01  0.11373E+02

APPROXIMATE FUNCTION VALUES

  0.99059E+01
********************************

SET VANE 1 TO   23.69 DEGREES

SET VANE 2 TO    9.46 DEGREES

SET VANE 3 TO    7.06 DEGREES

SET VANE 4 TO   11.37 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
SURGE MARGIN=    9.6600

********************************


PRECISE FUNCTION VALUES
  0.96800E+01


BEGIN ITERATION NUMBER   12

NOMINAL DESIGN NUMBER =   16

X-VECTOR
  0.23685E+02  0.94642E+01  0.70626E+01  0.11373E+02

FUNCTION VALUES
  0.96800E+01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.11755E+01  0.10896E+01  0.26895E+00 -0.30000E+01

X-VECTOR
  0.22510E+02  0.10554E+02  0.73316E+01  0.83727E+01

APPROXIMATE FUNCTION VALUES
  0.99175E+01
********************************

SET VANE 1 TO   22.51 DEGREES

SET VANE 2 TO   10.55 DEGREES

SET VANE 3 TO    7.33 DEGREES

SET VANE 4 TO    8.37 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
SURGE MARGIN=    9.9500
```

```
PRECISE FUNCTION VALUES
  0.99500E+01

BEGI  ITERATION NUMBER   13

NOMINAL DESIGN NUMBER =   17

X-VECTOR
  0.22510E+02  0.10554E+02  0.73316E+01  0.83727E+01

FUNCTION VALUES
  0.99500E+01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.64875E+00  0.49088E+00 -0.10047E+00 -0.17918E+01

X-VECTOR
  0.21861E+02  0.11045E+02  0.72311E+01  0.65809E+01

APPROXIMATE FUNCTION VALUES
  0.99370E+01
*********************************

SET VANE 1 TO   21.86 DEGREES

SET VANE 2 TO   11.04 DEGREES

SET VANE 3 TO    7.23 DEGREES

SET VANE 4 TO    6.58 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
SURGE MARGIN=   10.0700

*********************************

PRECISE FUNCTION VALUES
  0.10070E+02

BEGIN ITERATION NUMBER   14

NOMINAL DESIGN NUMBER =   18

X-VECTOR

  0.21861E+02  0.11045E+02  0.72311E+01  0.65809E+01

FUNCTION VALUES
  0.10070E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.16422E+01 -0.20345E+00 -0.76704E+00 -0.15809E+01

X-VECTOR
  0.20219E+02  0.10841E+02  0.64633E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.10127E+02
*********************************
```

```
SET VANE 1 TO   20.22 DEGREES

SET VANE 2 TO   10.84 DEGREES

SET VANE 3 TO    6.46 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
SURGE MARGIN=   10.2200

********************************


PRECISE FUNCTION VALUES
  0.10220E+02


BEGIN ITERATION NUMBER   15

NOMINAL DESIGN NUMBER =   19

X-VECTOR
  0.20219E+02  0.10841E+02  0.64633E+01  0.50000E+01

FUNCTION VALUES
  0.10220E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.14843E+01 -0.19052E+00 -0.14633E+01  0.0

X-VECTOR
  0.18734E+02  0.10651E+02  0.50000E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES

  0.10249E+02
********************************

SET VANE 1 TO   18.73 DEGREES

SET VANE 2 TO   10.65 DEGREES

SET VANE 3 TO    5.00 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
SURGE MARGIN=   10.2500

********************************


PRECISE FUNCTION VALUES
  0.10250E+02
```

```
BEGIN ITERATION NUMBER   16

NOMINAL DESIGN NUMBER =   20

X-VECTOR
  0.18734E+02  0.10651E+02  0.50000E+01  0.50000E+01

FUNCTION VALUES
  0.10250E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.30376E+00  0.76676E-01  0.0          -0.13762E-06

X-VECTOR
  0.18431E+02  0.10727E+02  0.50000E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.10251E+02
********************************

SET VANE 1 TO   18.43 DEGREES

SET VANE 2 TO   10.73 DEGREES

SET VANE 3 TO    5.00 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
SURGE MARGIN=   10.2200

PRECISE FUNCTION VALUES
  0.10220E+02

BEGIN ITERATION NUMBER   17

NOMINAL DESIGN NUMBER =   21

X-VECTOR
  0.18431E+02  0.10727E+02  0.50000E+01  0.50000E+01

FUNCTION VALUES
  0.10220E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.50583E+00 -0.12569E-01  0.31959E-02  0.0

X-VECTOR
  0.18937E+02  0.10715E+02  0.50032E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.10223E+02
********************************

SET VANE 1 TO   18.94 DEGREES

SET VANE 2 TO   10.71 DEGREES

SET VANE 3 TO    5.00 DEGREES

SET VANE 4 TO    5.00 DEGREES
```

```
HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
SURGE MARGIN=   10.3000

********************************

PRECISE FUNCTION VALUES
  0.10300E+02

FINAL RESULT OF APPROXIMATE OPTIMIZATION

NOMINAL DESIGN NUMBER =   22

X-VECTOR
  0.18937E+02  0.10715E+02  0.50032E+01  0.50000E+01

FUNCTION VALUES
  0.10300E+02

RESULTS OF APPROXIMATE ANALYSIS/OPTIMIZATION

TITLE
*************************************************

GLOBAL LOCATIONS OF X-VARIABLES
    1    2    3    4

GLOBAL LOCATIONS OF FUNCTIONS, F(X)
    6

APPROXIMATION IS BASED ON   22 DESIGNS

NOMINAL DESIGN IS DESIGN NUMBER   22

VALUES OF X-VARIABLES
   0.1894E+02   0.1071E+02   0.5003E+01   0.5000E+01

VALUES OF FUNCTIONS, F(X)
   0.1030E+02

COEFFICIENTS OF TAYLOR SERIES EXPANSION

PARAMETER    1 = GLOBAL VARIABLE    6

LINEAR TERMS, DEL F
  -0.1099E-01  -0.2025E-02  -0.1383E-01  -0.2630E-01

NON-LINEAR TERMS, H, BEGINING WITH DIAGONAL ELEMENT

ROW    1
  -0.1955E-01

ROW    2
  -0.1120E-01

ROW    3
  -0.1810E-02

ROW    4
  -0.6212E-02
```

AD-A119 379   PRATT AND WHITNEY AIRCRAFT GROUP WEST PALM BEACH FL G--ETC   F/G 21/5
OPTIMIZATION OF COMPRESSOR VANE AND BLEED SETTINGS. USER'S MANU--ETC(U)
JUN 81   J E GARBEROGLIO, J O SONG   F33615-79-C-2013
UNCLASSIFIED   PWA-FR-13996   AFWAL-TR-82-2078   NL

2 of 2

END
DATE
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OPTIMIZATION RESULTS

OBJECTIVE FUNCTION

GLOBAL LOCATION 6 FUNCTION VALUE 0.10300E+02

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	1	1	0.10000E+02	0.18937E+02	0.35000E+02
2	2	2	0.50000E+01	0.10715E+02	0.25000E+02
3	3	3	0.50000E+01	0.50032E+01	0.25000E+02
4	4	4	0.50000E+01	0.50000E+01	0.25000E+02

********* FINAL SOLUTION VALUES ********

VANE ANGLE FOR VANE 1 IS 18.94 DEGREES

VANE ANGLE FOR VANE 2 IS 10.71 DEGREES

VANE ANGLE FOR VANE 3 IS 5.00 DEGREES

VANE ANGLE FOR VANE 4 IS 5.00 DEGREES

SURGE MARGIN= 10.3000

RPMC WAS HELD CONSTANT AT 5567.50
DVS WAS HELD CONSTANT AT 76.78

PROGRAM CALLS TO ANALIZ

ICALC	CALLS
1	1
2	22
3	1

STATOR VANE OPTIMIZER
****

PROTOTYPE SOFTWARE CAPABLE OF GUIDING THE OPTIMIZATION OF

STATOR VANE AND BLEED SETTINGS IN A MULTI-STAGE COMPRESSOR

PREPARED FOR THE AIR FORCE AERO PROPULSION LABORATORY

UNDER CONTRACT F33615-79-C-2013

BY: PRATT & WHITNEY AIRCRAFT GROUP
GOVERNMENT PRODUCTS DIVISION

PLEASE HIT RETURN TO VIEW OPTIMIZATION GOAL MENU

NO	GOAL	OPTIMIZATION CONDITIONS RFMC	WC	PR	DVS	O.L.	CONSTRAINTS S.M.	EFF.
1	EFF	X	-	-	X	-	-	-
2	EFF	X	-	-	-	X	-	-
3	EFF	-	X	X	-	-	-	-
4	EFF	X	-	-	X	-	MIN	-
5	EFF	X	-	-	-	X	MIN	-
6	EFF	-	X	X	-	-	MIN	-
7	S.M.	X	-	-	X	-	-	-
8	S.M.	X	-	-	-	X	-	-
9	S.M.	-	X	X	-	-	-	-
10	S.M.	X	-	-	X	-	-	MIN
11	S.M.	X	-	-	-	X	-	MIN
12	S.M.	-	X	X	-	-	-	MIN
13	SM/BLD	X	X	-	-	-	-	-
14	MAX WC	X	-	-	-	X	MIN	MIN
15	MIN WC	X	-	-	-	X	MIN	MIN
16	PR	X	X	-	-	-	MIN	MIN
17	PR	X	-	-	-	X	MIN	MIN

YOU HAVE SELECTED TO OPTIMIZE EFFICIENCY HOLDING

CORRECTED SPEED (RFMC) AND DISCHARGE VALVE SETTING (DVS) CONSTANT

WHILE CONSTRAINING SURGE MARGIN TO A MINIMUM VALUE
HOLD RFMC CONSTANT AT 5567.500
HOLD DVS CONSTANT AT 76.779
OPTIMIZING 4 VANE ANGLE(S)
LOWER BOUND FOR VANE 1 IS 10.000
DO YOU AGREE? (Y/N)
LOWER BOUND FOR VANE 2 IS 5.000
DO YOU AGREE? (Y/N)
LOWER BOUND FOR VANE 3 IS 5.000
DO YOU AGREE? (Y/N)
LOWER BOUND FOR VANE 4 IS 5.000
DO YOU AGREE? (Y/N)
UPPER BOUND FOR VANE 1 IS 35.000
DO YOU AGREE? (Y/N)
UPPER BOUND FOR VANE 2 IS 25.000
DO YOU AGREE? (Y/N)

UPPER BOUND FOR VANE 3 IS 25.000
DO YOU AGREE? (Y/N)
UPPER BOUND FOR VANE 4 IS 25.000
DO YOU AGREE? (Y/N)
LOWER BOUND VALUE FOR SM IS 10.000
UPPER BOUND VALUE FOR SM IS 1000.000
INCREMENTAL VANE ANGLE VALUE FOR INITIAL VANE SETTING IS -2.00

TITLE:
****

CONTROL PARAMETERS:

CALCULATION CONTROL,	NCALC	=	6
NUMBER OF GLOBAL DESIGN VARIABLES,	NDV	=	4
NUMBER OF SENSITIVITY VARIABLES,	NSV	=	0
NUMBER OF FUNCTIONS IN TWO-SPACE,	N2VAR	=	0
NUMBER OF APPROXIMATING VAR.	NXAPRX	=	4
INPUT INFORMATION PRINT CODE,	IPNPUT	=	1
DEBUG PRINT CODE,	IPDBG	=	0

CALCULATION CONTROL, NCALC

VALUE	MEANING
1	SINGLE ANALYSIS
2	OPTIMIZATION
3	SENSITIVITY
4	TWO-VARIABLE FUNCTION SPACE
5	OPTIMUM SENSITIVITY
6	APPROXIMATE OPTIMIZATION

* * OPTIMIZATION INFORMATION

GLOBAL VARIABLE NUMBER OF OBJECTIVE = 7
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION) = 0.1000E+01

CONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVER-RIDE)

IPRINT	ITMAX	ICNDIR	NSCAL	ITRM	LINOBJ	NACMX1	NFDG
5	20	5	0	3	0	10	0

FDCH	FDCHM	CT	CTMIN
0.10000E-01	0.10000E-02	-0.50000E-01	0.40000E-02
CTL	CTLMIN	THETA	PHI
-0.10000E-01	0.10000E-02	0.10000E+01	0.0
DELFUN	DABFUN	ALFMAX	ABOBJ1
0.10000E-02	0.0	0.10000E+00	0.10000E+00

DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT

D. V. NO.	LOWER BOUND	UPPER BOUND	INITIAL VALUE	SCALE
1	0.10000E+02	0.35000E+02	0.27000E+02	0.0
2	0.50000E+01	0.25000E+02	0.16000E+02	0.0
3	0.50000E+01	0.25000E+02	0.13000E+02	0.0
4	0.50000E+01	0.25000E+02	0.90000E+01	0.0

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	MULTIPLYING FACTOR
1	1	1	0.10000E+01
2	2	2	0.10000E+01
3	3	3	0.10000E+01
4	4	4	0.10000E+01

CONSTRAINT INFORMATION

THERE ARE 1 CONSTRAINT SETS

ID	GLOBAL VAR. 1	GLOBAL VAR. 2	LINEAR ID	LOWER BOUND	NORMALIZATION FACTOR	UPPER BOUND	NORMALIZATION FACTOR
1	6	6	0	0.10000E+02	0.10000E+02	0.10000E+04	0.10000E+04

TOTAL NUMBER OF CONSTRAINED PARAMETERS = 1

```
* * APPROXIMATE ANALYSIS/OPTIMIZATION INFORMATION

NUMBER OF FUNCTIONS APPROXIMATED, NF  =    0
NUMBER OF INPUT X-VECTORS,        NPS  =    5
NUMBER OF INPUT X-F PAIRS,        NPFS =    0
X-VECTOR FROM ANALIZ,             NPA  =    0
NOMINAL DESIGN,                   INOM =    0
READ UNIT FOR X-VECTORS,         ISCRX =    5
READ UNIT FOR X-F PAIRS,        ISCRXF =    5
PRINT CONTROL,                  IPAPRX =    1

MINIMUM APPROXIMATING CYCLES,     KMIN =    5
MAXIMUM APPROXIMATING CYCLES,     KMAX =   17
MAXIMUM DESIGNS USED IN FIT,     NPMAX =   28
NOMINAL DESIGN PARAMETER,         JNOM =   28
X-LOCATION INPUT PARAMETER,     INXLOC =    0
F-LOCATION INPUT PARAMETER,     INFLOC =    0
TAYLER SERIES I.D. CODE,        MAXTRM =    2

DELTA-X BOUNDS FOR APPROXIMATE OPTIMIZATION
0.2000E+01  0.2000E+01  0.2000E+01  0.2000E+01

MULTIPLIER ON DELX,             XFACT1 =  0.1500E+01
MULTIPLIER ON DELX,             XFACT2 =  0.2000E+01

GLOBAL LOCATIONS OF X-VARIABLES
    1    2    3    4

GLOBAL LOCATIONS OF FUNCTIONS
    7    6

X-VECTORS INPUT FROM UNIT    5

NUMBER    1     DESIGN    1
0.2900E+02  0.1800E+02  0.1500E+02  0.1100E+02

NUMBER    2     DESIGN    2
0.2700E+02  0.1800E+02  0.1500E+02  0.1100E+02

NUMBER    3     DESIGN    3
0.2700E+02  0.1600E+02  0.1500E+02  0.1100E+02

NUMBER    4     DESIGN    4
0.2700E+02  0.1600E+02  0.1300E+02  0.1100E+02

NUMBER    5     DESIGN    5
0.2700E+02  0.1600E+02  0.1300E+02  0.9000E+01


* * ESTIMATED DATA STORAGE REQUIREMENTS

             REAL                               INTEGER
INPUT  EXECUTION  AVAILABLE        INPUT  EXECUTION  AVAILABLE
  37      335       5000             26       71       1000
*********************************

SET VANE 1 TO   29.00 DEGREES

SET VANE 2 TO   18.00 DEGREES
```

```
SET VANE 3 TO   15.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF        5567.500
HOLD DVS  CONSTANT AT A VALUE OF          76.779
EFFICIENCY=     87.1400

SURGE MARGIN=    8.2600

********************************

********************************

SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   18.00 DEGREES

SET VANE 3 TO   15.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF        5567.500
HOLD DVS  CONSTANT AT A VALUE OF          76.779
EFFICIENCY=     87.3200

SURGE MARGIN=    8.7500

********************************
SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   16.00 DEGREES

SET VANE 3 TO   15.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF        5567.500
HOLD DVS  CONSTANT AT A VALUE OF          76.779
EFFICIENCY=     87.2400

SURGE MARGIN=    8.8700

********************************

********************************

SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   16.00 DEGREES

SET VANE 3 TO   13.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF        5567.500
HOLD DVS  CONSTANT AT A VALUE OF          76.779
EFFICIENCY=     87.2800

SURGE MARGIN=    9.1200

********************************

********************************
```

```
SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   16.00 DEGREES

SET VANE 3 TO   13.00 DEGREES

SET VANE 4 TO    9.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
EFFICIENCY=     87.3300

SURGE MARGIN=    9.1800

APPROXIMATE OPTIMIZATION ITERATION HISTORY

APPROXIMATING FUNCTION    1 IS THE OBJECTIVE

APPROXIMATING FUNCTIONS ASSOCIATED WITH CONSTRAINTS
    2

DESIGN VARIABLE NUMBERS ASSOCIATED WITH APPROXIMATING VARIABLES
    1    2    3    4

BEGIN ITERATION NUMBER    1

NOMINAL DESIGN NUMBER =    5

X-VECTOR
  0.27000E+02  0.16000E+02  0.13000E+02  0.90000E+01

FUNCTION VALUES
  0.87330E+02  0.91800E+01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.20000E+01 -0.30343E+00 -0.20000E+01 -0.20000E+01

X-VECTOR
  0.25000E+02  0.15697E+02  0.11000E+02  0.70000E+01

APPROXIMATE FUNCTION VALUES
  0.87596E+02  0.99782E+01
********************************

SET VANE 1 TO   25.00 DEGREES

SET VANE 2 TO   15.70 DEGREES

SET VANE 3 TO   11.00 DEGREES

SET VANE 4 TO    7.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
EFFICIENCY=     87.5100

SURGE MARGIN=    9.6100

********************************

PRECISE FUNCTION VALUES
  0.87510E+02  0.96100E+01
```

```
BEGIN ITERATION NUMBER    2

NOMINAL DESIGN NUMBER =    6

X-VECTOR
  0.25000E+02  0.15697E+02  0.11000E+02  0.70000E+01

FUNCTION VALUES
  0.87510E+02  0.96100E+01


RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.46831E+00 -0.20000E+01 -0.20000E+01 -0.17435E+01

X-VECTOR
  0.24531E+02  0.13697E+02  0.90000E+01  0.52565E+01

APPROXIMATE FUNCTION VALUES
  0.87326E+02  0.10000E+02
********************************


SET VANE 1 TO   24.53 DEGREES

SET VANE 2 TO   13.70 DEGREES

SET VANE 3 TO    9.00 DEGREES

SET VANE 4 TO    5.26 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=     87.3400

SURGE MARGIN=    9.8000

********************************


PRECISE FUNCTION VALUES
  0.87340E+02  0.98000E+01


BEGIN ITERATION NUMBER    3

NOMINAL DESIGN NUMBER =    7

X-VECTOR
  0.24531E+02  0.13697E+02  0.90000E+01  0.52565E+01

FUNCTION VALUES
  0.87340E+02  0.98000E+01


RESULTS OF APPROXIMATE OPTIMIZATION
```

DELTA-X VECTOR
-0.97002E+00 0.30000E+01 -0.20000E+01 -0.25652E+00

X-VECTOR
0.23561E+02 0.16697E+02 0.70000E+01 0.50000E+01

APPROXIMATE FUNCTION VALUES
0.87758E+02 0.99999E+01
****

SET VANE 1 TO 23.56 DEGREES

SET VANE 2 TO 16.70 DEGREES

SET VANE 3 TO 7.00 DEGREES

SET VANE 4 TO 5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF 5567.500
HOLD DVS CONSTANT AT A VALUE OF 76.779
EFFICIENCY= 87.3500

SURGE MARGIN= 9.8300

****

PRECISE FUNCTION VALUES
0.87350E+02 0.98300E+01

BEGIN ITERATION NUMBER 4

NOMINAL DESIGN NUMBER = 8

X-VECTOR
0.23561E+02 0.16697E+02 0.70000E+01 0.50000E+01

FUNCTION VALUES
0.87350E+02 0.98300E+01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
0.11059E+01 -0.11585E+01 -0.41264E+00 0.18275E-06

X-VECTOR
0.24667E+02 0.15538E+02 0.65874E+01 0.50000E+01

APPROXIMATE FUNCTION VALUES
0.87100E+02 0.99807E+01
****

SET VANE 1 TO 24.67 DEGREES

```
SET VANE 2 TO   15.54 DEGREES

SET VANE 3 TO    6.59 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=     87.2900

SURGE MARGIN=    9.8300

*********************************


FRECISE FUNCTION VALUES
  0.87290E+02  0.98300E+01


BEGIN ITERATION NUMBER     5

NOMINAL DESIGN NUMBER =    9

X-VECTOR
  0.24567E+02  0.15538E+02  0.65374E+01  0.50000E+01

FUNCTION VALUES
  0.87290E+02  0.98300E+01


RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.93281E+00  0.40022E-01  0.70299E+00  0.37014E+00

X-VECTOR
  0.23734E+02  0.15578E+02  0.72904E+01  0.53701E+01

APPROXIMATE FUNCTION VALUES
  0.87100E+02  0.10033E+02
*********************************

SET VANE 1 TO   23.73 DEGREES

SET VANE 2 TO   15.58 DEGREES

SET VANE 3 TO    7.29 DEGREES

SET VANE 4 TO    5.37 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=     87.3900

SURGE MARGIN=   10.0000

*********************************
```

```
PRECISE FUNCTION VALUES
  0.87390E+02  0.10000E+02


BEGIN ITERATION NUMBER    6

NOMINAL DESIGN NUMBER =   10

X-VECTOR
  0.23734E+02  0.15578E+02  0.72904E+01  0.53701E+01

FUNCTION VALUES
  0.87390E+02  0.10000E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.30000E+01  0.30000E+01  0.18914E+01  0.30000E+01

X-VECTOR
  0.20734E+02  0.18578E+02  0.91818E+01  0.83701E+01

APPROXIMATE FUNCTION VALUES
  0.87347E+02  0.10666E+02
********************************

SET VANE 1 TO   20.73 DEGREES

SET VANE 2 TO   18.58 DEGREES

SET VANE 3 TO    9.18 DEGREES

SET VANE 4 TO    8.37 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=     87.2200

SURGE MARGIN=    9.7200

********************************


PRECISE FUNCTION VALUES
  0.87220E+02  0.97200E+01


BEGIN ITERATION NUMBER    7

NOMINAL DESIGN NUMBER =   11

X-VECTOR

  0.20734E+02  0.18578E+02  0.91818E+01  0.83701E+01

FUNCTION VALUES
  0.87220E+02  0.97200E+01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.13537E+01 -0.30000E+01 -0.45008E+00 -0.17061E+01

X-VECTOR
  0.22033E+02  0.15578E+02  0.87317E+01  0.66640E+01
```

APPROXIMATE FUNCTION VALUES
  0.87309E+02 0.99692E+01
****

SET VANE 1 TO   22.09 DEGREES

SET VANE 2 TO   15.58 DEGREES

SET VANE 3 TO   8.73 DEGREES

SET VANE 4 TO   6.66 DEGREES

HOLD RFMC CONSTANT AT A VALUE OF   5567.500
HOLD DVS CONSTANT AT A VALUE OF   76.779
EFFICIENCY=   87.4000

SURGE MARGIN=   9.8100

****

PRECISE FUNCTION VALUES
  0.87400E+02 0.98100E+01

BEGIN ITERATION NUMBER   8

NOMINAL DESIGN NUMBER =   12

X-VECTOR
  0.22088E+02 0.15578E+02 0.87317E+01 0.66640E+01

FUNCTION VALUES
  0.87400E+02 0.98100E+01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.94308E+00 0.56411E+00 -0.31326E+00 0.64617E+00

X-VECTOR
  0.23031E+02 0.16142E+02 0.84184E+01 0.73102E+01

APPROXIMATE FUNCTION VALUES
  0.87343E+02 0.99064E+01
****

SET VANE 1 TO   23.03 DEGREES

SET VANE 2 TO   16.14 DEGREES

SET VANE 3 TO   8.42 DEGREES

SET VANE 4 TO   7.31 DEGREES

HOLD RFMC CONSTANT AT A VALUE OF   5567.500
HOLD DVS CONSTANT AT A VALUE OF   76.779
EFFICIENCY=   87.4500

SURGE MARGIN=   9.9100

****

PRECISE FUNCTION VALUES
  0.87450E+02 0.99100E+01

```
BEGIN ITERATION NUMBER     9

NOMINAL DESIGN NUMBER =   13

X-VECTOR
  0.23031E+02  0.16142E+02  0.84184E+01  0.73102E+01

FUNCTION VALUES
  0.87450E+02  0.99100E+01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.66503E+00 -0.73410E+00 -0.10000E+01  0.93294E+00

X-VECTOR
  0.23696E+02  0.15408E+02  0.74184E+01  0.82431E+01

APPROXIMATE FUNCTION VALUES
  0.87436E+02  0.10003E+02
********************************

SET VANE 1 TO   23.70 DEGREES

SET VANE 2 TO   15.41 DEGREES

SET VANE 3 TO    7.42 DEGREES

SET VANE 4 TO    8.24 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=      87.3900

SURGE MARGIN=    9.9000

********************************

PRECISE FUNCTION VALUES
  0.87390E+02  0.99000E+01

FINAL RESULT OF APPROXIMATE OPTIMIZATION

NOMINAL DESIGN NUMBER =   10

X-VECTOR
  0.23734E+02  0.15578E+02  0.72904E+01  0.53701E+01

FUNCTION VALUES
  0.87390E+02  0.10000E+02

RESULTS OF APPROXIMATE ANALYSIS/OPTIMIZATION

TITLE
**********************************************************

GLOBAL LOCATIONS OF X-VARIABLES
    1    2    3    4

GLOBAL LOCATIONS OF FUNCTIONS, F(X)
    7    6
```

```
APPROXIMATION IS BASED ON   14 DESIGNS

NOMINAL DESIGN IS DESIGN NUMBER   10

VALUES OF X-VARIABLES
   0.2373E+02   0.1558E+02   0.7290E+01   0.5370E+01

VALUES OF FUNCTIONS, F(X)
   0.8739E+02   0.1000E+02

COEFFICIENTS OF TAYLOR SERIES EXPANSION

PARAMETER    1 = GLOBAL VARIABLE    7

LINEAR TERMS, DEL F
   0.1275E-01   0.2707E-01   0.3280E-01   0.2149E-01

NON-LINEAR TERMS, H, BEGINING WITH DIAGONAL ELEMENT

ROW    1
  -0.2542E-01

ROW    2
  -0.2431E-01

ROW    3
  -0.4392E-02

ROW    4
  -0.1624E-01

PARAMETER    2 = GLOBAL VARIABLE    6

LINEAR TERMS, DEL F
  -0.5497E-01  -0.9764E-02  -0.2890E-01  -0.2887E-01

NON-LINEAR TERMS, H, BEGINING WITH DIAGONAL ELEMENT

ROW    1
  -0.4194E-01

ROW    2
  -0.3187E-01

ROW    3
  -0.1430E-01

ROW    4
   0.5455E-02
```

OPTIMIZATION RESULTS

OBJECTIVE FUNCTION
GLOBAL LOCATION 7 FUNCTION VALUE 0.87390E+02

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	1	1	0.10000E+02	0.23734E+02	0.35000E+02
2	2	2	0.50000E+01	0.15578E+02	0.25000E+02
3	3	3	0.50000E+01	0.72904E+01	0.25000E+02
4	4	4	0.50000E+01	0.53701E+01	0.25000E+02

DESIGN CONSTRAINTS

ID	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	6	0.10000E+02	0.10000E+02	0.10000E+04

********* FINAL SOLUTION VALUES ********

VANE ANGLE FOR VANE 1 IS 23.73 DEGREES

VANE ANGLE FOR VANE 2 IS 15.58 DEGREES

VANE ANGLE FOR VANE 3 IS 7.29 DEGREES

VANE ANGLE FOR VANE 4 IS 5.37 DEGREES

EFFICIENCY= 87.3900

SURGE MARGIN= 10.0000

RPMC WAS HELD CONSTANT AT 5567.50
DVS WAS HELD CONSTANT AT 76.78

PROGRAM CALLS TO ANALIZ

ICALC	CALLS
1	1
2	14
3	1

STATOR VANE OPTIMIZER
****

PROTOTYPE SOFTWARE CAPABLE OF GUIDING THE OPTIMIZATION OF

STATOR VANE AND BLEED SETTINGS IN A MULTI-STAGE COMPRESSOR

PREPARED FOR THE AIR FORCE AERO PROPULSION LABORATORY

UNDER CONTRACT F33615-79-C-2013

BY: PRATT & WHITNEY AIRCRAFT GROUP
GOVERNMENT PRODUCTS DIVISION

PLEASE HIT RETURN TO VIEW OPTIMIZATION GOAL MENU

		OPTIMIZATION CONDITIONS					CONSTRAINTS	
NO	GOAL	RPMC	WC	FR	DVS	O.L.	S.M.	EFF
1	EFF	X	-	-	X	-	-	-
2	EFF	X	-	-	-	X	-	-
3	EFF	-	X	X	-	-	-	-
4	EFF	X	-	-	X	-	MIN	-
5	EFF	X	-	-	-	X	MIN	-
6	EFF	-	X	X	-	-	MIN	-
7	S.M.	X	-	-	X	-	-	-
8	S.M.	X	-	-	-	X	-	-
9	S.M.	-	X	X	-	-	-	-
10	S.M.	X	-	-	X	-	-	MIN
11	S.M.	X	-	-	-	X	-	MIN
12	S.M.	-	X	X	-	-	-	MIN
13	SM/BLD	X	X	-	-	-	-	-
14	MAX WC	X	-	-	-	X	MIN	MIN
15	MIN WC	X	-	-	-	X	MIN	MIN
16	PR	X	X	-	-	-	MIN	MIN
17	PR	X	-	-	-	X	MIN	MIN

YOU HAVE SELECTED TO OPTIMIZE EFFICIENCY HOLDING

CORRECTED SPEED (RPMC) AND DISCHARGE VALVE SETTING (DVS) CONSTANT

```
WHILE CONSTRAINING SURGE MARGIN TO A MINIMUM VALUE
HOLD RPMC CONSTANT AT   5567.500
HOLD DVS  CONSTANT AT     76.779
OPTIMIZING 4 VANE ANGLE(S)
LOWER BOUND FOR VANE 1 IS     10.000
DO YOU AGREE? (Y/N)
LOWER BOUND FOR VANE 2 IS      5.000
DO YOU AGREE? (Y/N)
LOWER BOUND FOR VANE 3 IS      5.000
DO YOU AGREE? (Y/N)
LOWER BOUND FOR VANE 4 IS      5.000
DO YOU AGREE? (Y/N)
UPPER BOUND FOR VANE 1 IS     35.000
DO YOU AGREE? (Y/N)
UPPER BOUND FOR VANE 2 IS     25.000
DO YOU AGREE? (Y/N)

UPPER BOUND FOR VANE 3 IS     25.000
DO YOU AGREE? (Y/N)
UPPER BOUND FOR VANE 4 IS     25.000
DO YOU AGREE? (Y/N)
LOWER BOUND VALUE FOR SM    IS      10.000
UPPER BOUND VALUE FOR SM    IS    1000.000
INCREMENTAL VANE ANGLE VALUE FOR INITIAL VANE SETTING IS    -2.00
```

```
TITLE:
*************************************************************************

CONTROL PARAMETERS;
CALCULATION CONTROL,                       NCALC =    6
NUMBER OF GLOBAL DESIGN VARIABLES,           NDV =    4
NUMBER OF SENSITIVITY VARIABLES,             NSV =    0
NUMBER OF FUNCTIONS IN TWO-SPACE,          N2VAR =    0
NUMBER OF APPROXIMATING VAR.              NXAPRX =    4
INPUT INFORMATION PRINT CODE,             IPNPUT =    1
DEBUG PRINT CODE,                          IPDBG =    0

CALCULATION CONTROL, NCALC
VALUE   MEANING
  1     SINGLE ANALYSIS
  2     OPTIMIZATION
  3     SENSITIVITY
  4     TWO-VARIABLE FUNCTION SPACE
  5     OPTIMUM SENSITIVITY
  6     APPROXIMATE OPTIMIZATION


* * OPTIMIZATION INFORMATION

GLOBAL VARIABLE NUMBER OF OBJECTIVE             =     7
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION) = 0.1000E+01

CONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVER-RIDE)

IPRINT  ITMAX   ICNDIR   NSCAL   ITRM   LINOBJ  NACMX1   NFDG
   5      20      5        0       3       0      10       0

 FDCH              FDCHM             CT                CTMIN
 0.10000E-01       0.10000E-02      -0.50000E-01       0.40000E-02

 CTL               CTLMIN            THETA             PHI
-0.10000E-01       0.10000E-02       0.10000E+01       0.0

 DELFUN            DABFUN            ALPHAX            ABOBJ1
 0.10000E-02       0.0               0.10000E+00       0.10000E+00

DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT
D. V.      LOWER          UPPER          INITIAL
NO.        BOUND          BOUND           VALUE         SCALE
  1      0.10000E+02    0.35000E+02    0.27000E+02     0.0
  2      0.50000E+01    0.25000E+02    0.16000E+02     0.0
  3      0.50000E+01    0.25000E+02    0.13000E+02     0.0
  4      0.50000E+01    0.25000E+02    0.90000E+01     0.0


DESIGN VARIABLES
       D. V.     GLOBAL     MULTIPLYING
ID      NO.     VAR. NO.      FACTOR
 1       1         1       0.10000E+01

 2       2         2       0.10000E+01
 3       3         3       0.10000E+01
 4       4         4       0.10000E+01

CONSTRAINT INFORMATION

THERE ARE  1 CONSTRAINT SETS
     GLOBAL  GLOBAL  LINEAR      LOWER      NORMALIZATION      UPPER      NORMALIZATION
ID   VAR. 1  VAR. 2    ID        BOUND         FACTOR          BOUND         FACTOR
 1     6       6       0      0.10000E+02    0.10000E+02    0.10000E+04    0.10000E+04

TOTAL NUMBER OF CONSTRAINED PARAMETERS =    1
```

```
* * APPROXIMATE ANALYSIS/OPTIMIZATION INFORMATION

NUMBER OF FUNCTIONS APPROXIMATED, NF =      0
NUMBER OF INPUT X-VECTORS,          NPS =   5
NUMBER OF INPUT X-F PAIRS,         NPFS =   0
X-VECTOR FROM ANALIZ,               NPA =   0
NOMINAL DESIGN,                    INOM =   0
READ UNIT FOR X-VECTORS,          ISCRX =   5
READ UNIT FOR X-F PAIRS,         ISCRXF =   5
PRINT CONTROL,                   IPAPRX =   1

MINIMUM APPROXIMATING CYCLES,      KMIN =   5
MAXIMUM APPROXIMATING CYCLES,      KMAX =  17
MAXIMUM DESIGNS USED IN FIT,      NPMAX =  28
NOMINAL DESIGN PARAMETER,          JNOM =  28
X-LOCATION INPUT PARAMETER,      INXLOC =   0
F-LOCATION INPUT PARAMETER,      INFLOC =   0
TAYLER SERIES I.D. CODE,         MAXTRM =   2

DELTA-X BOUNDS FOR APPROXIMATE OPTIMIZATION
0.2000E+01  0.2000E+01  0.2000E+01  0.2000E+01

MULTIPLIER ON DELX,             XFACT1 =  0.1500E+01
MULTIPLIER ON DELX,             XFACT2 =  0.2000E+01

GLOBAL LOCATIONS OF X-VARIABLES
    1    2    3    4

GLOBAL LOCATIONS OF FUNCTIONS
    7    6

X-VECTORS INPUT FROM UNIT    5

NUMBER     1      DESIGN     1
0.2900E+02  0.1800E+02  0.1500E+02  0.1100E+02

NUMBER     2      DESIGN     2
0.2700E+02  0.1800E+02  0.1500E+02  0.1100E+02

NUMBER     3      DESIGN     3
0.2700E+02  0.1600E+02  0.1500E+02  0.1100E+02

NUMBER     4      DESIGN     4
0.2700E+02  0.1600E+02  0.1300E+02  0.1100E+02

NUMBER     5      DESIGN     5
0.2700E+02  0.1600E+02  0.1300E+02  0.9000E+01

* * ESTIMATED DATA STORAGE REQUIREMENTS

            REAL                              INTEGER
 INPUT  EXECUTION  AVAILABLE       INPUT  EXECUTION  AVAILABLE
   37      335       5000            26       71       1000
********************************
```

```
SET VANE 1 TO   29.00 DEGREES

SET VANE 2 TO   18.00 DEGREES

SET VANE 3 TO   15.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
EFFICIENCY=     87.1800

SURGE MARGIN=     8.2200

********************************

********************************

SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   18.00 DEGREES

SET VANE 3 TO   15.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
EFFICIENCY=     87.3000

SURGE MARGIN=     8.7900

********************************

SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   16.00 DEGREES

SET VANE 3 TO   15.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
EFFICIENCY=     87.2100

SURGE MARGIN=     8.9600

********************************

********************************

SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   16.00 DEGREES

SET VANE 3 TO   13.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
EFFICIENCY=     87.3100

SURGE MARGIN=     9.1000

********************************
```

```
********************************

SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   16.00 DEGREES

SET VANE 3 TO   13.00 DEGREES

SET VANE 4 TO    9.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
EFFICIENCY=     87.4200

SURGE MARGIN=     9.2400

APPROXIMATE OPTIMIZATION ITERATION HISTORY

APPROXIMATING FUNCTION    1 IS THE OBJECTIVE

APPROXIMATING FUNCTIONS ASSOCIATED WITH CONSTRAINTS
    2

DESIGN VARIABLE NUMBERS ASSOCIATED WITH APPROXIMATING VARIABLES
    1    2    3    4

BEGIN ITERATION NUMBER    1

NOMINAL DESIGN NUMBER =    5

X-VECTOR
  0.27000E+02  0.16000E+02  0.13000E+02  0.90000E+01

FUNCTION VALUES
  0.87420E+02  0.92400E+01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.20000E+01  0.11166E+01 -0.20000E+01 -0.20000E+01

X-VECTOR
  0.25000E+02  0.17117E+02  0.11000E+02  0.70000E+01

APPROXIMATE FUNCTION VALUES
  0.87300E+02  0.99951E+01
********************************

SET VANE 1 TO   25.00 DEGREES

SET VANE 2 TO   17.12 DEGREES

SET VANE 3 TO   11.00 DEGREES

SET VANE 4 TO    7.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
EFFICIENCY=     87.5100

SURGE MARGIN=     9.4400

********************************

PRECISE FUNCTION VALUES
  0.87510E+02  0.94400E+01
```

```
BEGIN ITERATION NUMBER    2

NOMINAL DESIGN NUMBER =    6

X-VECTOR
  0.25000E+02  0.17117E+02  0.11000E+02  0.70000E+01

FUNCTION VALUES
  0.87510E+02  0.94400E+01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.97329E+00 -0.20000E+01 -0.20000E+01 -0.20000E+01

X-VECTOR
  0.25973E+02  0.15117E+02  0.90000E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.87749E+02  0.99521E+01
*********************************

SET VANE 1 TO   25.97 DEGREES

SET VANE 2 TO   15.12 DEGREES

SET VANE 3 TO    9.00 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=     87.2800

SURGE MARGIN=    9.6600

*********************************

PRECISE FUNCTION VALUES
  0.87280E+02  0.96600E+01

BEGIN ITERATION NUMBER    3

NOMINAL DESIGN NUMBER =    7

X-VECTOR
  0.25973E+02  0.15117E+02  0.90000E+01  0.50000E+01

FUNCTION VALUES
  0.87280E+02  0.96600E+01

RESULTS OF APPROXIMATE OPTIMIZATION
```

```
DELTA-X VECTOR
  0.55595E+00  0.16977E+01 -0.20000E+01 -0.13585E-05

X-VECTOR
  0.26529E+02  0.16814E+02  0.70000E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.82094E+02  0.10006E+02
*******************************

SET VANE 1 TO   26.53 DEGREES

SET VANE 2 TO   16.81 DEGREES

SET VANE 3 TO    7.00 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=     87.0800

SURGE MARGIN=    9.4600

*******************************

PRECISE FUNCTION VALUES
  0.87080E+02  0.94600E+01

BEGIN ITERATION NUMBER    4

NOMINAL DESIGN NUMBER =    8

X-VECTOR
  0.26529E+02  0.16814E+02  0.70000E+01  0.50000E+01

FUNCTION VALUES
  0.87080E+02  0.94600E+01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.80326E+00 -0.14797E+01  0.30000E+01  0.43284E-06

X-VECTOR
  0.25726E+02  0.15335E+02  0.10000E+02  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.87424E+02  0.96890E+01
*******************************

SET VANE 1 TO   25.73 DEGREES

SET VANE 2 TO   15.33 DEGREES

SET VANE 3 TO   10.00 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=     87.3300

SURGE MARGIN=    9.6600
```

```
PRECISE FUNCTION VALUES
  0.87330E+02  0.96600E+01

BEGIN ITERATION NUMBER    5

NOMINAL DESIGN NUMBER =    9

X-VECTOR
  0.25726E+02  0.15335E+02  0.10000E+02  0.50000E+01

FUNCTION VALUES
  0.87330E+02  0.96600E+01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.31087E+00 -0.20260E+01 -0.34839E+00  0.29043E-06

X-VECTOR
  0.25415E+02  0.13309E+02  0.96516E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.87494E+02  0.97115E+01
*********************************

SET VANE 1 TO   25.42 DEGREES

SET VANE 2 TO   13.31 DEGREES

SET VANE 3 TO    9.65 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPNC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=    87.2200

SURGE MARGIN=    9.6900

*********************************

PRECISE FUNCTION VALUES
  0.87220E+02  0.96900E+01

BEGIN ITERATION NUMBER    6

NOMINAL DESIGN NUMBER =   10

X-VECTOR
  0.25415E+02  0.13309E+02  0.96516E+01  0.50000E+01

FUNCTION VALUES
  0.87220E+02  0.96900E+01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.10068E+00  0.48789E+00  0.45810E-01  0.64493E-06

X-VECTOR
  0.25516E+02  0.13796E+02  0.96974E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.87249E+02  0.96945E+01
*********************************
```

SET VANE 1 TO 25.52 DEGREES

SET VANE 2 TO 13.80 DEGREES

SET VANE 3 TO 9.70 DEGREES

SET VANE 4 TO 5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF 5567.500
HOLD DVS CONSTANT AT A VALUE OF 76.779
EFFICIENCY= 87.2900

SURGE MARGIN= 9.7700

****

PRECISE FUNCTION VALUES
0.87290E+02 0.97700E+01

BEGIN ITERATION NUMBER 7

NOMINAL DESIGN NUMBER = 11

X-VECTOR

0.25516E+02 0.13796E+02 0.96974E+01 0.50000E+01

FUNCTION VALUES
0.87290E+02 0.97700E+01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
-0.95330E-01 -0.10000E+01 0.11300E-01 0.0

X-VECTOR
0.25420E+02 0.12796E+02 0.97087E+01 0.50000E+01

APPROXIMATE FUNCTION VALUES
0.87260E+02 0.97947E+01
****

SET VANE 1 TO 25.42 DEGREES

SET VANE 2 TO 12.80 DEGREES

SET VANE 3 TO 9.71 DEGREES

SET VANE 4 TO 5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF 5567.500
HOLD DVS CONSTANT AT A VALUE OF 76.779
EFFICIENCY= 87.1900

SURGE MARGIN= 9.6100

****

PRECISE FUNCTION VALUES
0.87190E+02 0.96100E+01

```
BEGIN ITERATION NUMBER    8

NOMINAL DESIGN NUMBER =   12

X-VECTOR
  0.25420E+02  0.12796E+02  0.97087E+01  0.50000E+01

FUNCTION VALUES
  0.87190E+02  0.96100E+01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.17329E+00  0.20423E+01  0.27320E+00  0.23133E-06

X-VECTOR
  0.25247E+02  0.14839E+02  0.99819E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.87334E+02  0.97163E+01
*********************************

SET VANE 1 TO   25.25 DEGREES

SET VANE 2 TO   14.84 DEGREES

SET VANE 3 TO    9.98 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
EFFICIENCY=     87.3100

SURGE MARGIN=    9.8100

*********************************

PRECISE FUNCTION VALUES
  0.87310E+02  0.98100E+01

BEGIN ITERATION NUMBER    9

NOMINAL DESIGN NUMBER =   13

X-VECTOR
  0.25247E+02  0.14839E+02  0.99819E+01  0.50000E+01

FUNCTION VALUES
  0.87310E+02  0.98100E+01

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.22920E+01  0.81894E-02  0.26147E+00  0.24356E-06

X-VECTOR
  0.22955E+02  0.14847E+02  0.10243E+02  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.87189E+02  0.99417E+01
*********************************
```

```
SET VANE 1 TO   22.96 DEGREES

SET VANE 2 TO   14.85 DEGREES

SET VANE 3 TO   10.24 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
EFFICIENCY=     87.3200

SURGE MARGIN=    9.9200

*********************************


PRECISE FUNCTION VALUES
  0.87320E+02  0.99200E+01


BEGIN ITERATION NUMBER   10

NOMINAL DESIGN NUMBER =   14

X-VECTOR
  0.22955E+02  0.14847E+02  0.10243E+02  0.50000E+01

FUNCTION VALUES
  0.87320E+02  0.99200E+01


RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.31324E+00 -0.12231E+00 -0.10000E+01  0.10213E-06

X-VECTOR
  0.22642E+02  0.14725E+02  0.92434E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.87239E+02  0.99342E+01
*********************************

SET VANE 1 TO   22.64 DEGREES

SET VANE 2 TO   14.72 DEGREES

SET VANE 3 TO    9.24 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
EFFICIENCY=     87.3800

SURGE MARGIN=    9.9800

*********************************


PRECISE FUNCTION VALUES
  0.87380E+02  0.99800E+01
```

```
FINAL RESULT OF APPROXIMATE OPTIMIZATION

NOMINAL DESIGN NUMBER =    15

X-VECTOR
  0.22642E+02  0.14725E+02  0.92434E+01  0.50000E+01

FUNCTION VALUES
  0.87380E+02  0.99800E+01

RESULTS OF APPROXIMATE ANALYSIS/OPTIMIZATION

TITLE
*********************************************************

GLOBAL LOCATIONS OF X-VARIABLES
    1    2    3    4

GLOBAL LOCATIONS OF FUNCTIONS, F(X)
    7    6

APPROXIMATION IS BASED ON   15 DESIGNS

NOMINAL DESIGN IS DESIGN NUMBER   15

VALUES OF X-VARIABLES
   0.2264E+02   0.1472E+02   0.9243E+01   0.5000E+01

VALUES OF FUNCTIONS, F(X)
   0.8738E+02   0.9980E+01

COEFFICIENTS OF TAYLOR SERIES EXPANSION

PARAMETER     1 = GLOBAL VARIABLE     7

LINEAR TERMS, DEL F
  -0.3983E-01   0.3550E-01   0.5171E-01   0.7911E-01

NON-LINEAR TERMS, H, BEGINING WITH DIAGONAL ELEMENT

ROW    1
   0.6057E-03

ROW    2
  -0.8705E-02

ROW    3
  -0.2149E-01

ROW    4
  -0.2440E-01

PARAMETER     2 = GLOBAL VARIABLE     6

LINEAR TERMS, DEL F
  -0.2371E-01  -0.7503E-02  -0.1890E-01  -0.3944E-01

NON-LINEAR TERMS, H, BEGINING WITH DIAGONAL ELEMENT
```

ROW 1
-0.3965E-01

ROW 2
-0.6655E-01

ROW 3
-0.3313E-02

ROW 4
-0.1871E-03

OPTIMIZATION RESULTS

OBJECTIVE FUNCTION
GLOBAL LOCATION 7 FUNCTION VALUE 0.87380E+02

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	1	1	0.10000E+02	0.22642E+02	0.35000E+02
2	2	2	0.50000E+01	0.14725E [illegible]	0.25000E+02
3	3	3	0.50000E+01	0.92434E+01	0.25000E+02
4	4	4	0.50000E+01	0.50000E+01	0.25000E+02

DESIGN CONSTRAINTS

ID	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	6	0.10000E+02	0.99800E+01	0.10000E+04

********* FINAL SOLUTION VALUES ********

VANE ANGLE FOR VANE 1 IS 22.64 DEGREES

VANE ANGLE FOR VANE 2 IS 14.72 DEGREES

VANE ANGLE FOR VANE 3 IS 9.24 DEGREES

VANE ANGLE FOR VANE 4 IS 5.00 DEGREES

EFFICIENCY= 87.3800

SURGE MARGIN= 9.9800

RPMC WAS HELD CONSTANT AT 5567.50
DVS WAS HELD CONSTANT AT 76.78

PROGRAM CALLS TO ANALIZ

ICALC	CALLS
1	1
2	15
3	1

STATOR VANE OPTIMIZER
****

PROTOTYPE SOFTWARE CAPABLE OF GUIDING THE OPTIMIZATION OF

STATOR VANE AND BLEED SETTINGS IN A MULTI-STAGE COMPRESSOR

PREPARED FOR THE AIR FORCE AERO PROPULSION LABORATORY

UNDER CONTRACT F33615-79-C-2013

BY: PRATT & WHITNEY AIRCRAFT GROUP
GOVERNMENT PRODUCTS DIVISION

PLEASE HIT RETURN TO VIEW OPTIMIZATION GOAL MENU

NO	GOAL	OPTIMIZATION CONDITIONS RPMC	WC	PR	DVS	O.L.	CONSTRAINTS S.M.	EFF
1	EFF	X	-	-	X	-	-	-
2	EFF	X	-	-	-	X	-	-
3	EFF	-	X	X	-	-	-	-
4	EFF	X	-	-	X	-	MIN	-
5	EFF	X	-	-	-	X	MIN	-
6	EFF	-	X	X	-	-	MIN	-
7	S.M.	X	-	-	X	-	-	-
8	S.M.	X	-	-	-	X	-	-
9	S.M.	-	X	X	-	-	-	-
10	S.M.	X	-	-	X	-	-	MIN
11	S.M.	X	-	-	-	X	-	MIN
12	S.M.	-	X	X	-	-	-	MIN
13	SM/BLD	X	X	-	-	-	-	-
14	MAX WC	X	-	-	-	X	MIN	MIN
15	MIN WC	X	-	-	-	X	MIN	MIN
16	FR	X	X	-	-	-	MIN	MIN
17	PR	X	-	-	-	X	MIN	MIN

```
YOU HAVE SELECTED TO OPTIMIZE SURGE MARGIN HOLDING

CORRECTED SPEED (RPMC) AND DISCHARGE VALVE SETTING (DVS) CONSTANT

WHILE CONSTRAINING EFFICIENCY TO A MINIMUM VALUE
HOLD RPMC CONSTANT AT     5567.500
HOLD DVS  CONSTANT AT       76.779
OPTIMIZING 4 VANE ANGLE(S)
LOWER BOUND FOR VANE 1 IS     10.000
DO YOU AGREE? (Y/N)
LOWER BOUND FOR VANE 2 IS      5.000
DO YOU AGREE? (Y/N)
LOWER BOUND FOR VANE 3 IS      5.000
DO YOU AGREE? (Y/N)
LOWER BOUND FOR VANE 4 IS      5.000
DO YOU AGREE? (Y/N)
UPPER BOUND FOR VANE 1 IS     35.000
DO YOU AGREE? (Y/N)
UPPER BOUND FOR VANE 2 IS     25.000
DO YOU AGREE? (Y/N)

UPPER BOUND FOR VANE 3 IS     25.000
DO YOU AGREE? (Y/N)
UPPER BOUND FOR VANE 4 IS     25.000
DO YOU AGREE? (Y/N)
LOWER BOUND VALUE FOR EFF   IS      87.300
UPPER BOUND VALUE FOR EFF   IS    1000.000
INCREMENTAL VANE ANGLE VALUE FOR INITIAL VANE SETTING IS    -2.00
```

```
TITLE:
****************************************************************.

CONTROL PARAMETERS;
CALCULATION CONTROL,                    NCALC =    6
NUMBER OF GLOBAL DESIGN VARIABLES,       NDV =    4
NUMBER OF SENSITIVITY VARIABLES,         NSV =    0
NUMBER OF FUNCTIONS IN TWO-SPACE,      N2VAR =    0
NUMBER OF APPROXIMATING VAR.          NXAPRX =    4
INPUT INFORMATION PRINT CODE,         IPNPUT =    1
DEBUG PRINT CODE,                      IFDBG =    0

CALCULATION CONTROL, NCALC
VALUE   MEANING
  1     SINGLE ANALYSIS
  2     OPTIMIZATION
  3     SENSITIVITY
  4     TWO-VARIABLE FUNCTION SPACE
  5     OPTIMUM SENSITIVITY
  6     APPROXIMATE OPTIMIZATION


* * OPTIMIZATION INFORMATION

GLOBAL VARIABLE NUMBER OF OBJECTIVE          =     6
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION) =  0.1000E+01

CONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVER-RIDE)

IPRINT  ITMAX  ICNDIR  NSCAL  ITRM  LINOBJ  NACMX1  NFDG
  5      20      5       0      3      0      10      0

 FDCH           FDCHM          CT             CTMIN
 0.10000E-01    0.10000E-02   -0.50000E-01    0.40000E-02

 CTL            CTLMIN         THETA          PHI
-0.10000E-01    0.10000E-02    0.10000E+01    0.0

 DELFUN         DABFUN         ALPHAX         ABOBJ1
 0.10000E-02    0.0            0.10000E+00    0.10000E+00

DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT
D. V.      LOWER        UPPER        INITIAL
NO.        BOUND        BOUND        VALUE          SCALE
 1      0.10000E+02  0.35000E+02  0.27000E+02    0.0
 2      0.50000E+01  0.25000E+02  0.16000E+02    0.0
 3      0.50000E+01  0.25000E+02  0.13000E+02    0.0
 4      0.50000E+01  0.25000E+02  0.90000E+01    0.0

DESIGN VARIABLES
      D. V.     GLOBAL     MULTIPLYING
ID     NO.     VAR. NO.      FACTOR
 1      1          1       0.10000E+01

 2      2          2       0.10000E+01
 3      3          3       0.10000E+01
 4      4          4       0.10000E+01

CONSTRAINT INFORMATION

THERE ARE  1 CONSTRAINT SETS
      GLOBAL  GLOBAL  LINEAR     LOWER      NORMALIZATION     UPPER      NORMALIZATION
 ID   VAR. 1  VAR. 2    ID       BOUND         FACTOR         BOUND         FACTOR
  1      7       7       0    0.87300E+02   0.87300E+02   0.10000E+04   0.10000E+04

TOTAL NUMBER OF CONSTRAINED PARAMETERS =    1
```

```
* * APPROXIMATE ANALYSIS/OPTIMIZATION INFORMATION

NUMBER OF FUNCTIONS APPROXIMATED, NF =      0
NUMBER OF INPUT X-VECTORS,        NPS =      5
NUMBER OF INPUT X-F PAIRS,       NPFS =      0
X-VECTOR FROM ANALIZ,             NPA =      0
NOMINAL DESIGN,                  INOM =      0
READ UNIT FOR X-VECTORS,        ISCRX =      5
READ UNIT FOR X-F PAIRS,       ISCRXF =      5
PRINT CONTROL,                 IPAPRX =      1

MINIMUM APPROXIMATING CYCLES,    KMIN =      5
MAXIMUM APPROXIMATING CYCLES,    KMAX =     17
MAXIMUM DESIGNS USED IN FIT,    NFMAX =     28
NOMINAL DESIGN PARAMETER,        JNOM =     28
X-LOCATION INPUT PARAMETER,    INXLOC =      0
F-LOCATION INPUT PARAMETER,    INFLOC =      0
TAYLER SERIES I.D. CODE,       MAXTRM =      2

DELTA-X BOUNDS FOR APPROXIMATE OPTIMIZATION
0.2000E+01  0.2000E+01  0.2000E+01  0.2000E+01

MULTIPLIER ON DELX,            XFACT1 =  0.1500E+01
MULTIPLIER ON DELX,            XFACT2 =  0.2000E+01

GLOBAL LOCATIONS OF X-VARIABLES
    1    2    3    4

GLOBAL LOCATIONS OF FUNCTIONS
    6    7

X-VECTORS INPUT FROM UNIT    5

NUMBER    1     DESIGN    1
0.2900E+02  0.1800E+02  0.1500E+02  0.1100E+02

NUMBER    2     DESIGN    2
0.2700E+02  0.1800E+02  0.1500E+02  0.1100E+02

NUMBER    3     DESIGN    3
0.2700E+02  0.1600E+02  0.1500E+02  0.1100E+02

NUMBER    4     DESIGN    4
0.2700E+02  0.1600E+02  0.1300E+02  0.1100E+02

NUMBER    5     DESIGN    5
0.2700E+02  0.1600E+02  0.1300E+02  0.9000E+01

* * ESTIMATED DATA STORAGE REQUIREMENTS

           REAL                          INTEGER
INPUT  EXECUTION  AVAILABLE    INPUT  EXECUTION  AVAILABLE
  37       335       5000        26        71        1000
*************************************

SET VANE 1 TO   29.00 DEGREES

SET VANE 2 TO   18.00 DEGREES
```

SET VANE 3 TO 15.00 DEGREES

SET VANE 4 TO 11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF 5567.500
HOLD DVS CONSTANT AT A VALUE OF 76.779
SURGE MARGIN= 8.2600

EFFICIENCY= 87.1400

****

****

SET VANE 1 TO 27.00 DEGREES

SET VANE 2 TO 18.00 DEGREES

SET VANE 3 TO 15.00 DEGREES

SET VANE 4 TO 11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF 5567.500
HOLD DVS CONSTANT AT A VALUE OF 76.779
SURGE MARGIN= 8.7500

EFFICIENCY= 87.3200

****

SET VANE 1 TO 27.00 DEGREES

SET VANE 2 TO 16.00 DEGREES

SET VANE 3 TO 15.00 DEGREES

SET VANE 4 TO 11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF 5567.500
HOLD DVS CONSTANT AT A VALUE OF 76.779
SURGE MARGIN= 8.8700

EFFICIENCY= 87.2400

****

****

SET VANE 1 TO 27.00 DEGREES

SET VANE 2 TO 16.00 DEGREES

SET VANE 3 TO 13.00 DEGREES

SET VANE 4 TO 11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF 5567.500
HOLD DVS CONSTANT AT A VALUE OF 76.779
SURGE MARGIN= 9.1200

EFFICIENCY= 87.2800

****

****

```
SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   16.00 DEGREES

SET VANE 3 TO   13.00 DEGREES

SET VANE 4 TO    9.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
SURGE MARGIN=     9.1800

EFFICIENCY=      87.3300

********************************
 APPROXIMATE OPTIMIZATION ITERATION HISTORY

 APPROXIMATING FUNCTION     1 IS THE OBJECTIVE

 APPROXIMATING FUNCTIONS ASSOCIATED WITH CONSTRAINTS
     2

 DESIGN VARIABLE NUMBERS ASSOCIATED WITH APPROXIMATING VARIABLES
     1    2    3    4

 BEGIN ITERATION NUMBER     1

 NOMINAL DESIGN NUMBER =    5

 X-VECTOR
   0.27000E+02  0.16000E+02  0.13000E+02  0.90000E+01

 FUNCTION VALUES
   0.91800E+01  0.87330E+02

 RESULTS OF APPROXIMATE OPTIMIZATION

 DELTA-X VECTOR
  -0.20000E+01  0.82847E+00 -0.20000E+01 -0.20000E+01

 X-VECTOR
   0.25000E+02  0.16828E+02  0.11000E+02  0.70000E+01

 APPROXIMATE FUNCTION VALUES
   0.99303E+01  0.87633E+02
********************************

SET VANE 1 TO   25.00 DEGREES

SET VANE 2 TO   16.83 DEGREES

SET VANE 3 TO   11.00 DEGREES

SET VANE 4 TO    7.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
SURGE MARGIN=     9.4800

EFFICIENCY=      87.5400

********************************


 PRECISE FUNCTION VALUES
   0.94800E+01  0.87540E+02
```

```
BEGIN ITERATION NUMBER    2

NOMINAL DESIGN NUMBER =    6

X-VECTOR
  0.25000E+02  0.16828E+02  0.11000E+02  0.70000E+01

FUNCTION VALUES
  0.94800E+01  0.87540E+02


RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.42508E+00  0.84746E+00 -0.20000E+01 -0.20000E+01

X-VECTOR
  0.25425E+02  0.17676E+02  0.90000E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.97684E+01  0.87653E+02
********************************


SET VANE 1 TO   25.43 DEGREES

SET VANE 2 TO   17.68 DEGREES

SET VANE 3 TO    9.00 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
SURGE MARGIN=    9.6500

EFFICIENCY=     87.3700

********************************



PRECISE FUNCTION VALUES
  0.96500E+01  0.87370E+02


BEGIN ITERATION NUMBER    3

NOMINAL DESIGN NUMBER =    7

X-VECTOR
  0.25425E+02  0.17676E+02  0.90000E+01  0.50000E+01

FUNCTION VALUES
  0.96500E+01  0.87370E+02


RESULTS OF APPROXIMATE OPTIMIZATION
```

```
DELTA-X VECTOR
  0.18055E+01 -0.71106E+00 -0.20000E+01 -0.28566E-05

X-VECTOR
  0.27231E+02  0.16965E+02  0.70000E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.10846E+02  0.89697E+02
********************************

SET VANE 1 TO   27.23 DEGREES

SET VANE 2 TO   16.96 DEGREES

SET VANE 3 TO    7.00 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF     5567.500
HOLD DVS  CONSTANT AT A VALUE OF       76.779
SURGE MARGIN=    9.4500

EFFICIENCY=    87.0500

********************************


PRECISE FUNCTION VALUES
  0.94500E+01  0.87050E+02


BEGIN ITERATION NUMBER    4

NOMINAL DESIGN NUMBER =    8

X-VECTOR
  0.27231E+02  0.16965E+02  0.70000E+01  0.50000E+01

FUNCTION VALUES
  0.94500E+01  0.87050E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.26999E+01 -0.10758E+01  0.30000E+01  0.0

X-VECTOR
  0.24531E+02  0.15889E+02  0.10000E+02  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.98537E+01  0.87274E+02
********************************

SET VANE 1 TO   24.53 DEGREES

SET VANE 2 TO   15.89 DEGREES

SET VANE 3 TO   10.00 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF     5567.500
HOLD DVS  CONSTANT AT A VALUE OF       76.779
SURGE MARGIN=    9.7900

EFFICIENCY=    87.4300

********************************
```

```
PRECISE FUNCTION VALUES
  0.97900E+01  0.87430E+02

BEGIN ITERATION NUMBER    5

NOMINAL DESIGN NUMBER =    9

X-VECTOR
  0.24531E+02  0.15889E+02  0.10000E+02  0.50000E+01

FUNCTION VALUES
  0.97900E+01  0.87430E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.13657E+01 -0.30000E+01 -0.12498E+00  0.71604E+00

X-VECTOR
  0.23165E+02  0.12889E+02  0.98750E+01  0.57160E+01

APPROXIMATE FUNCTION VALUES
  0.10994E+02  0.87442E+02
********************************

SET VANE 1 TO   23.16 DEGREES

SET VANE 2 TO   12.89 DEGREES

SET VANE 3 TO    9.88 DEGREES

SET VANE 4 TO    5.72 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
SURGE MARGIN=    9.9800

EFFICIENCY=     87.2700

********************************

PRECISE FUNCTION VALUES
  0.99800E+01  0.87270E+02

BEGIN ITERATION NUMBER    6

NOMINAL DESIGN NUMBER =   10

X-VECTOR
  0.23165E+02  0.12889E+02  0.98750E+01  0.57160E+01

FUNCTION VALUES
  0.99800E+01  0.87270E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.52440E+00  0.58893E+00  0.98662E+00 -0.71604E+00

X-VECTOR
  0.23689E+02  0.13478E+02  0.10862E+02  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.10025E+02  0.87293E+02
********************************
```

```
SET VANE 1 TO   23.69 DEGREES

SET VANE 2 TO   13.48 DEGREES

SET VANE 3 TO   10.86 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
SURGE MARGIN=    9.8400

EFFICIENCY=     87.3000

********************************



PRECISE FUNCTION VALUES
  0.98400E+01  0.87300E+02


BEGIN ITERATION NUMBER    7

NOMINAL DESIGN NUMBER =   11

X-VECTOR

  0.23689E+02  0.13478E+02  0.10862E+02  0.50000E+01

FUNCTION VALUES
  0.98400E+01  0.87300E+02


RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.14401E+01  0.74872E+00 -0.29438E+01  0.29881E+01

X-VECTOR
  0.22249E+02  0.14227E+02  0.79178E+01  0.79881E+01

APPROXIMATE FUNCTION VALUES
  0.99222E+01  0.87495E+02
********************************


SET VANE 1 TO   22.25 DEGREES

SET VANE 2 TO   14.23 DEGREES

SET VANE 3 TO    7.92 DEGREES

SET VANE 4 TO    7.99 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
SURGE MARGIN=    9.9000

EFFICIENCY=     87.3000

********************************



PRECISE FUNCTION VALUES
  0.99000E+01  0.87300E+02
```

```
BEGIN ITERATION NUMBER    8

NOMINAL DESIGN NUMBER =   12

X-VECTOR
  0.22249E+02  0.14227E+02  0.79178E+01  0.79881E+01

FUNCTION VALUES
  0.99000E+01  0.87300E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.31456E+00  0.25967E+00  0.62168E+00 -0.27062E+01

X-VECTOR
  0.22564E+02  0.14486E+02  0.85395E+01  0.52819E+01

APPROXIMATE FUNCTION VALUES
  0.99291E+01  0.87331E+02
********************************

SET VANE 1 TO   22.56 DEGREES

SET VANE 2 TO   14.49 DEGREES

SET VANE 3 TO    8.54 DEGREES

SET VANE 4 TO    5.28 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
SURGE MARGIN=    9.9700

EFFICIENCY=    87.3600

********************************

PRECISE FUNCTION VALUES
  0.99700E+01  0.87360E+02

BEGIN ITERATION NUMBER    9

NOMINAL DESIGN NUMBER =   13

X-VECTOR
  0.22564E+02  0.14486E+02  0.85395E+01  0.52819E+01

FUNCTION VALUES
  0.99700E+01  0.87360E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.26179E+00 -0.69402E-01  0.10623E+00 -0.28189E+00

X-VECTOR
  0.22302E+02  0.14417E+02  0.86457E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.99761E+01  0.87370E+02
********************************
```

```
SET VANE 1 TO   22.30 DEGREES

SET VANE 2 TO   14.42 DEGREES

SET VANE 3 TO    8.65 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
SURGE MARGIN=   10.0100

EFFICIENCY=     87.3200

********************************


PRECISE FUNCTION VALUES
  0.10010E+02  0.87320E+02


BEGIN ITERATION NUMBER   10

NOMINAL DESIGN NUMBER =   14

X-VECTOR
  0.22302E+02  0.14417E+02  0.86457E+01  0.50000E+01

FUNCTION VALUES
  0.10010E+02  0.87320E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.14109E+00 -0.50324E-01  0.14968E-01  0.58275E-06

X-VECTOR
  0.22160E+02  0.14367E+02  0.86607E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.10010E+02  0.87321E+02
********************************

SET VANE 1 TO   22.16 DEGREES

SET VANE 2 TO   14.37 DEGREES

SET VANE 3 TO    8.66 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
SURGE MARGIN=   10.0200

EFFICIENCY=     87.3100

********************************


PRECISE FUNCTION VALUES
  0.10020E+02  0.87310E+02
```

```
BEGIN ITERATION NUMBER  11

NOMINAL DESIGN NUMBER =   15

X-VECTOR
  0.22160E+02  0.14367E+02  0.86607E+01  0.50000E+01

FUNCTION VALUES
  0.10020E+02  0.87310E+02


RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.92877E-01 -0.16467E-01  0.23182E-02  0.0

X-VECTOR
  0.22067E+02  0.14350E+02  0.86630E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.10020E+02  0.87310E+02
********************************


SET VANE 1 TO   22.07 DEGREES

SET VANE 2 TO   14.35 DEGREES

SET VANE 3 TO    8.66 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
SURGE MARGIN=    9.9200

EFFICIENCY=    87.3200

********************************


PRECISE FUNCTION VALUES
  0.99200E+01  0.87320E+02


BEGIN ITERATION NUMBER   12

NOMINAL DESIGN NUMBER =   16

X-VECTOR
  0.22067E+02  0.14350E+02  0.86630E+01  0.50000E+01

FUNCTION VALUES
  0.99200E+01  0.87320E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.90472E+00  0.24113E+00  0.33393E+00  0.76387E-01

X-VECTOR
  0.22972E+02  0.14591E+02  0.89970E+01  0.50764E+01

APPROXIMATE FUNCTION VALUES
  0.99321E+01  0.87341E+02
********************************
```

```
SET VANE 1 TO   22.97 DEGREES

SET VANE 2 TO   14.59 DEGREES

SET VANE 3 TO    9.00 DEGREES

SET VANE 4 TO    5.08 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
SURGE MARGIN=    9.9000

EFFICIENCY=     87.3900

*********************************


PRECISE FUNCTION VALUES
  0.99000E+01  0.87390E+02


BEGIN ITERATION NUMBER   13

NOMINAL DESIGN NUMBER =   17

X-VECTOR
  0.22972E+02  0.14591E+02  0.89970E+01  0.50764E+01

FUNCTION VALUES
  0.99000E+01  0.87390E+02


RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.53803E+00 -0.10465E+00  0.24495E-01 -0.76386E-01

X-VECTOR
  0.22434E+02  0.14487E+02  0.90215E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.99036E+01  0.87397E+02
*********************************

SET VANE 1 TO   22.43 DEGREES

SET VANE 2 TO   14.49 DEGREES

SET VANE 3 TO    9.02 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
SURGE MARGIN=    9.9600

EFFICIENCY=     87.3400

*********************************


PRECISE FUNCTION VALUES
  0.99600E+01  0.87340E+02


BEGIN ITERATION NUMBER   14

NOMINAL DESIGN NUMBER =   18
```

```
X-VECTOR
  0.22434E+02  0.14487E+02  0.90215E+01  0.50000E+01

FUNCTION VALUES
  0.99600E+01  0.87340E+02


RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.10636E+00  0.82121E-01 -0.61548E-01  0.20496E-06

X-VECTOR
  0.22540E+02  0.14569E+02  0.89599E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.99602E+01  0.87340E+02
********************************

SET VANE 1 TO   22.54 DEGREES

SET VANE 2 TO   14.57 DEGREES

SET VANE 3 TO    8.96 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD DVS  CONSTANT AT A VALUE OF        76.779
SURGE MARGIN=   10.0300

EFFICIENCY=     87.3400

********************************


PRECISE FUNCTION VALUES
  0.10030E+02  0.87340E+02


BEGIN ITERATION NUMBER   15

NOMINAL DESIGN NUMBER =   19

X-VECTOR
  0.22540E+02  0.14569E+02  0.89599E+01  0.50000E+01

FUNCTION VALUES
  0.10030E+02  0.87340E+02


RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.65381E+00  0.13942E+00 -0.15637E+00  0.37472E-06

X-VECTOR
  0.21886E+02  0.14708E+02  0.88035E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.10035E+02  0.87350E+02
********************************

SET VANE 1 TO   21.89 DEGREES

SET VANE 2 TO   14.71 DEGREES
```

```
SET VANE 3 TO    8.80 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
SURGE MARGIN=    9.9900

EFFICIENCY=     87.3100

********************************

PRECISE FUNCTION VALUES
  0.99900E+01  0.87310E+02

BEGIN ITERATION NUMBER   16

NOMINAL DESIGN NUMBER =   20

X-VECTOR
  0.21896E+02  0.14708E+02  0.88035E+01  0.50000E+01

FUNCTION VALUES
  0.99900E+01  0.87310E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.45081E+00 -0.16517E+00  0.65177E-01  0.81430E-06

X-VECTOR
  0.22337E+02  0.14543E+02  0.88687E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.99925E+01  0.87315E+02
********************************

SET VANE 1 TO   22.34 DEGREES

SET VANE 2 TO   14.54 DEGREES

SET VANE 3 TO    8.87 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD DVS  CONSTANT AT A VALUE OF         76.779
SURGE MARGIN=   10.0900

EFFICIENCY=     87.3200
********************************

PRECISE FUNCTION VALUES
  0.10090E+02  0.87320E+02

BEGIN ITERATION NUMBER   17

NOMINAL DESIGN NUMBER =   21

X-VECTOR
  0.22337E+02  0.14543E+02  0.88687E+01  0.50000E+01
```

FUNCTION VALUES
0.10090E+02 0.87320E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
-0.15458E+01 0.61068E+00 0.32988E+00 0.50180E-06

X-VECTOR
0.20791E+02 0.15154E+02 0.91986E+01 0.50000E+01

APPROXIMATE FUNCTION VALUES
0.10122E+02 0.87355E+02
****

SET VANE 1 TO 20.79 DEGREES

SET VANE 2 TO 15.15 DEGREES

SET VANE 3 TO 9.20 DEGREES

SET VANE 4 TO 5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF 5567.500
HOLD DVS CONSTANT AT A VALUE OF 76.779
SURGE MARGIN= 10.0900

EFFICIENCY= 87.2600

****

PRECISE FUNCTION VALUES
0.10000E+02 0.87260E+02

FINAL RESULT OF APPROXIMATE OPTIMIZATION

NOMINAL DESIGN NUMBER = 21

X-VECTOR
0.22337E+02 0.14543E+02 0.88687E+01 0.50000E+01

FUNCTION VALUES
0.10090E+02 0.87320E+02

RESULTS OF APPROXIMATE ANALYSIS/OPTIMIZATION

TITLE
****

GLOBAL LOCATIONS OF X-VARIABLES
1 2 3 4

GLOBAL LOCATIONS OF FUNCTIONS, F(X)
6 7

APPROXIMATION IS BASED ON 22 DESIGNS

NOMINAL DESIGN IS DESIGN NUMBER 21

VALUES OF X-VARIABLES
0.2234E+02 0.1454E+02 0.8869E+01 0.5000E+01

VALUES OF FUNCTIONS, F(X)
0.1009E+02 0.8732E+02

COEFFICIENTS OF TAYLOR SERIES EXPANSION

PARAMETER 1 = GLOBAL VARIABLE 6

LINEAR TERMS, DEL F
-0.2489E-01 -0.1656E-01 -0.3135E-01 -0.1033E+00

NON-LINEAR TERMS, H, BEGINING WITH DIAGONAL ELEMENT

ROW 1
-0.3420E-01

ROW 2
-0.3243E-01

ROW 3
-0.1605E-01

ROW 4
0.2657E-01

PARAMETER 2 = GLOBAL VARIABLE 7

LINEAR TERMS, DEL F
0.1970E-01 0.6028E-01 0.4993E-01 0.4308E-01

NON-LINEAR TERMS, H, BEGINING WITH DIAGONAL ELEMENT

ROW 1
-0.2774E-01

ROW 2
-0.1114E-01

ROW 3
-0.1144E-01

ROW 4
-0.1471E-01

OPTIMIZATION RESULTS

OBJECTIVE FUNCTION
GLOBAL LOCATION 6 FUNCTION VALUE 0.10090E+02

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	1	1	0.10000E+02	0.22337E+02	0.35000E+02
2	2	2	0.50000E+01	0.14543E+02	0.25000E+02
3	3	3	0.50000E+01	0.88687E+01	0.25000E+02
4	4	4	0.50000E+01	0.50000E+01	0.25000E+02

DESIGN CONSTRAINTS

ID	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	7	0.87300E+02	0.87320E+02	0.10000E+04

********* FINAL SOLUTION VALUES ********

VANE ANGLE FOR VANE 1 IS 22.34 DEGREES

VANE ANGLE FOR VANE 2 IS 14.54 DEGREES

VANE ANGLE FOR VANE 3 IS 8.87 DEGREES

VANE ANGLE FOR VANE 4 IS 5.00 DEGREES

SURGE MARGIN= 10.0900

EFFICIENCY= 87.3200

RPMC WAS HELD CONSTANT AT 5567.50
DVS WAS HELD CONSTANT AT 76.78

PROGRAM CALLS TO ANALIZ

ICALC	CALLS
1	1
2	22
3	1

```
                         STATOR VANE OPTIMIZER
                         *********************
      PROTOTYPE SOFTWARE CAPABLE OF GUIDING THE OPTIMIZATION OF

      STATOR VANE AND BLEED SETTINGS IN A MULTI-STAGE COMPRESSOR


      PREPARED FOR THE AIR FORCE AERO PROPULSION LABORATORY

      UNDER CONTRACT F33615-79-C-2013

      BY: PRATT & WHITNEY AIRCRAFT GROUP
          GOVERNMENT PRODUCTS DIVISION



      PLEASE HIT RETURN TO VIEW OPTIMIZATION GOAL MENU
 ----------------------------------------------------------
              I OPTIMIZATION CONDITIONS I CONSTRAINTS I
 NO I  GOAL   I RPMC  WC   FR  DVS  O.L. I S.M. I EFF  I
 ---+---------+--------------------------+------+-------
  1 I   EFF   I  X    -    -    X    -   I  -   I  -   I
  2 I   EFF   I  X    -    -    -    X   I  -   I  -   I
  3 I   EFF   I  -    X    X    -    -   I  -   I  -   I
  4 I   EFF   I  X    -    -    X    -   I MIN  I  -   I
  5 I   EFF   I  X    -    -    -    X   I MIN  I  -   I
  6 I   EFF   I  -    X    X    -    -   I MIN  I  -   I
  7 I  S.M.   I  X    -    -    X    -   I  -   I  -   I
  8 I  S.M.   I  X    -    -    -    X   I  -   I  -   I
  9 I  S.M.   I  -    X    X    -    -   I  -   I  -   I
 10 I  S.M.   I  X    -    -    X    -   I  -   I MIN  I
 11 I  S.M.   I  X    -    -    -    X   I  -   I MIN  I
 12 I  S.M.   I  -    X    X    -    -   I  -   I MIN  I
 13 I SM/BLD  I  X    X    -    -    -   I  -   I  -   I
 14 I MAX WC  I  X    -    -    -    X   I MIN  I MIN  I
 15 I MIN WC  I  X    -    -    -    X   I MIN  I MIN  I
 16 I   FR    I  X    X    -    -    -   I MIN  I MIN  I
 17 I   PR    I  X    -    -    -    X   I MIN  I MIN  I
 YOU HAVE SELECTED TO MAXIMIZE CORRECTED FLOW HOLDING

 CORRECTED SPEED (RPMC) AND OPERATING LINE (OL) CONSTANT

 WHILE CONSTRAINING SURGE MARGIN AND EFFICIENCY TO MINIMUM VALUES
 HOLD RPMC CONSTANT AT    5567.500
 HOLD OL   CONSTANT AT      76.779
 OPTIMIZING 4 VANE ANGLE(S)
 LOWER BOUND FOR VANE 1 IS    10.000
 DO YOU AGREE? (Y/N)
 LOWER BOUND FOR VANE 2 IS     5.000
 DO YOU AGREE? (Y/N)
 LOWER BOUND FOR VANE 3 IS     5.000
 DO YOU AGREE? (Y/N)
 LOWER BOUND FOR VANE 4 IS     5.000
 DO YOU AGREE? (Y/N)
 UPPER BOUND FOR VANE 1 IS    35.000
 DO YOU AGREE? (Y/N)
 UPPER BOUND FOR VANE 2 IS    25.000
 DO YOU AGREE? (Y/N)

 UPPER BOUND FOR VANE 3 IS    25.000
 DO YOU AGREE? (Y/N)
 UPPER BOUND FOR VANE 4 IS    25.000
 DO YOU AGREE? (Y/N)
 LOWER BOUND VALUE FOR SM    IS       8.500
 UPPER BOUND VALUE FOR SM    IS     100.000
 LOWER BOUND VALUE FOR EFF   IS      87.000
 UPPER BOUND VALUE FOR EFF   IS    1000.000
 INCREMENTAL VANE ANGLE VALUE FOR INITIAL VANE SETTING IS     -2.00
```

TITLE:
****

CONTROL PARAMETERS;

CALCULATION CONTROL,	NCALC	=	6
NUMBER OF GLOBAL DESIGN VARIABLES,	NDV	=	4
NUMBER OF SENSITIVITY VARIABLES,	NSV	=	0
NUMBER OF FUNCTIONS IN TWO-SPACE,	N2VAR	=	0
NUMBER OF APPROXIMATING VAR.	NXAPRX	=	4
INPUT INFORMATION PRINT CODE,	IFNPUT	=	1
DEBUG PRINT CODE,	IPDBG	=	0

CALCULATION CONTROL, NCALC

VALUE	MEANING
1	SINGLE ANALYSIS
2	OPTIMIZATION
3	SENSITIVITY
4	TWO-VARIABLE FUNCTION SPACE
5	OPTIMUM SENSITIVITY
6	APPROXIMATE OPTIMIZATION

* * OPTIMIZATION INFORMATION

GLOBAL VARIABLE NUMBER OF OBJECTIVE = 8
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION) = 0.1000E+01

CONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVER-RIDE)

IPRINT	ITMAX	ICNDIR	NSCAL	ITRM	LINOBJ	NACMX1	NFDG
5	20	5	0	3	0	10	0

FDCH	FDCHM	CT	CTMIN
0.10000E-01	0.10000E-02	-0.50000E-01	0.40000E-02

CTL	CTLMIN	THETA	PHI
-0.10000E-01	0.10000E-02	0.10000E+01	0.0

DELFUN	DABFUN	ALPHAX	ABOBJ1
0.10000E-02	0.0	0.10000E+00	0.10000E+00

DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT

D. V. NO.	LOWER BOUND	UPPER BOUND	INITIAL VALUE	SCALE
1	0.10000E+02	0.35000E+02	0.27000E+02	0.0
2	0.50000E+01	0.25000E+02	0.16000E+02	0.0
3	0.50000E+01	0.25000E+02	0.13000E+02	0.0
4	0.50000E+01	0.25000E+02	0.90000E+01	0.0

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	MULTIPLYING FACTOR
1	1	1	0.10000E+01
2	2	2	0.10000E+01
3	3	3	0.10000E+01
4	4	4	0.10000E+01

CONSTRAINT INFORMATION

THERE ARE 2 CONSTRAINT SETS

ID	GLOBAL VAR. 1	GLOBAL VAR. 2	LINEAR ID	LOWER BOUND	NORMALIZATION FACTOR	UPPER BOUND	NORMALIZATION FACTOR
1	6	6	0	0.85000E+01	0.85000E+01	0.10000E+03	0.10000E+03
3	7	7	0	0.87000E+02	0.87000E+02	0.10000E+04	0.10000E+04

TOTAL NUMBER OF CONSTRAINED PARAMETERS = 2

* * APPROXIMATE ANALYSIS/OPTIMIZATION INFORMATION

```
NUMBER OF FUNCTIONS APPROXIMATED, NF  =   0
NUMBER OF INPUT X-VECTORS,        NPS  =   5
NUMBER OF INPUT X-F PAIRS,        NPFS =   0
X-VECTOR FROM ANALIZ,             NPA  =   0
NOMINAL DESIGN,                   INOM =   0
READ UNIT FOR X-VECTORS,        ISCRX  =   5
READ UNIT FOR X-F PAIRS,        ISCRXF =   5
PRINT CONTROL,                  IPAFRX =   1

MINIMUM APPROXIMATING CYCLES,     KMIN =   5
MAXIMUM APPROXIMATING CYCLES,     KMAX =  17
MAXIMUM DESIGNS USED IN FIT,     NFMAX =  28
NOMINAL DESIGN PARAMETER,         JNOM =  28
X-LOCATION INPUT PARAMETER,     INXLOC =   0
F-LOCATION INPUT PARAMETER,     INFLOC =   0
TAYLOR SERIES I.D. CODE,        MAXTRM =   2

DELTA-X BOUNDS FOR APPROXIMATE OPTIMIZATION
0.2000E+01  0.2000E+01  0.2000E+01  0.2000E+01

MULTIPLIER ON DELX,             XFACT1 =  0.1500E+01
MULTIPLIER ON DELX,             XFACT2 =  0.2000E+01

GLOBAL LOCATIONS OF X-VARIABLES
    1    2    3    4

GLOBAL LOCATIONS OF FUNCTIONS
    8    6    7

X-VECTORS INPUT FROM UNIT     5

NUMBER    1      DESIGN    1
0.2900E+02  0.1800E+02  0.1500E+02  0.1100E+02

NUMBER    2      DESIGN    2

0.2700E+02  0.1800E+02  0.1500E+02  0.1100E+02

NUMBER    3      DESIGN    3
0.2700E+02  0.1600E+02  0.1500E+02  0.1100E+02

NUMBER    4      DESIGN    4
0.2700E+02  0.1600E+02  0.1300E+02  0.1100E+02

NUMBER    5      DESIGN    5
0.2700E+02  0.1600E+02  0.1300E+02  0.9000E+01
```

```
* * ESTIMATED DATA STORAGE REQUIREMENTS

              REAL                               INTEGER
     INPUT  EXECUTION  AVAILABLE        INPUT  EXECUTION  AVAILABLE
       41      355       5000             30       78       1000
   *********************************

     SET VANE 1 TO    29.00 DEGREES

     SET VANE 2 TO    18.00 DEGREES

     SET VANE 3 TO    15.00 DEGREES

     SET VANE 4 TO    11.00 DEGREES

     HOLD RPMC CONSTANT AT A VALUE OF       5567.500
     HOLD OL   CONSTANT AT A VALUE OF         76.779
     CORRECTED FLOW= 77.5200

     SURGE MARGIN=     8.2800

     EFFICIENCY=      87.1400

   *********************************

   *********************************

     SET VANE 1 TO    27.00 DEGREES

     SET VANE 2 TO    18.00 DEGREES

     SET VANE 3 TO    15.00 DEGREES

     SET VANE 4 TO    11.00 DEGREES

     HOLD RPMC CONSTANT AT A VALUE OF       5567.500
     HOLD OL   CONSTANT AT A VALUE OF         76.779
     CORRECTED FLOW= 78.4100

     SURGE MARGIN=     8.7700

     EFFICIENCY=      87.3200

   *********************************

   *********************************

     SET VANE 1 TO    27.00 DEGREES

     SET VANE 2 TO    16.00 DEGREES

     SET VANE 3 TO    15.00 DEGREES

     SET VANE 4 TO    11.00 DEGREES

     HOLD RPMC CONSTANT AT A VALUE OF       5567.500
     HOLD OL   CONSTANT AT A VALUE OF         76.779
     CORRECTED FLOW= 78.7800

     SURGE MARGIN=     8.8100

     EFFICIENCY=      87.2500

   *********************************
```

```
********************************

SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   16.00 DEGREES

SET VANE 3 TO   13.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF        5567.500
HOLD CL   CONSTANT AT A VALUE OF          76.779
CORRECTED FLOW= 79.1900

SURGE MARGIN=     8.9700

EFFICIENCY=      87.3000

********************************

********************************

SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   16.00 DEGREES

SET VANE 3 TO   13.00 DEGREES

SET VANE 4 TO    9.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF        5567.500
HOLD CL   CONSTANT AT A VALUE OF          76.779
CORRECTED FLOW= 79.4900

SURGE MARGIN=     9.2000

EFFICIENCY=      87.3300

********************************

APPROXIMATE OPTIMIZATION ITERATION HISTORY

APPROXIMATING FUNCTION     1 IS THE OBJECTIVE

APPROXIMATING FUNCTIONS ASSOCIATED WITH CONSTRAINTS
    2    3

DESIGN VARIABLE NUMBERS ASSOCIATED WITH APPROXIMATING VARIABLES
    1    2    3    4

BEGIN ITERATION NUMBER     1

NOMINAL DESIGN NUMBER =     5

X-VECTOR
  0.27000E+02  0.16000E+02  0.13000E+02  0.90000E+01

FUNCTION VALUES
  0.79490E+02  0.92000E+01  0.87330E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.20000E+01 -0.20000E+01 -0.20000E+01 -0.20000E+01
```

```
X-VECTOR
  0.25000E+02  0.14000E+02  0.11000E+02  0.70000E+01

APPROXIMATE FUNCTION VALUES
  0.81460E+02  0.10120E+02  0.87520E+02
********************************

SET VANE 1 TO   25.00 DEGREES

SET VANE 2 TO   14.00 DEGREES

SET VANE 3 TO   11.00 DEGREES

SET VANE 4 TO    7.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD OL   CONSTANT AT A VALUE OF        76.779
CORRECTED FLOW= 81.2800

SURGE MARGIN=    9.6700

EFFICIENCY=     87.4000

********************************

PRECISE FUNCTION VALUES
  0.81280E+02  0.96700E+01  0.87400E+02

BEGIN ITERATION NUMBER    2

NOMINAL DESIGN NUMBER =    6

X-VECTOR
  0.25000E+02  0.14000E+02  0.11000E+02  0.70000E+01

FUNCTION VALUES
  0.81280E+02  0.96700E+01  0.87400E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.19352E+01 -0.12170E+01 -0.20000E+01 -0.20000E+01

X-VECTOR
  0.23065E+02  0.12783E+02  0.90000E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.82731E+02  0.96947E+01  0.87381E+02
********************************

SET VANE 1 TO   23.06 DEGREES

SET VANE 2 TO   12.78 DEGREES

SET VANE 3 TO    9.00 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD OL   CONSTANT AT A VALUE OF        76.779
CORRECTED FLOW= 82.7400

SURGE MARGIN=    9.9900

EFFICIENCY=     87.2500
```

```
*******************************

PRECISE FUNCTION VALUES
  0.82740E+02  0.99900E+01  0.87250E+02


BEGIN ITERATION NUMBER    3

NOMINAL DESIGN NUMBER =     7

X-VECTOR
  0.23065E+02  0.12783E+02  0.90000E+01  0.50000E+01

FUNCTION VALUES
  0.82740E+02  0.99900E+01  0.87250E+02

RESULTS OF APPROXIMATE OPTIMIZATION

OPTIMIZATION HAS PRODUCED AN X-VECTOR WHICH IS THE SAME AS A PREVIOUS DESIGN

DELTA-X VECTOR
  0.84560E-06 -0.56198E-05 -0.40702E-05 -0.29150E-05

X-VECTOR
  0.23065E+02  0.12783E+02  0.90000E+01  0.50000E+01

THE FOLLOWING DESIGN IS NOT THE APPROXIMATE OPTIMUM

DELTA-X VECTOR
  0.60001E-01  0.59994E-01  0.39996E-01  0.19997E-01

X-VECTOR
  0.23125E+02  0.12843E+02  0.90400E+01  0.50200E+01

APPROXIMATE FUNCTION VALUES
  0.82704E+02  0.99970E+01  0.87256E+02
*******************************


SET VANE 1 TO    23.12 DEGREES

SET VANE 2 TO    12.84 DEGREES

SET VANE 3 TO     9.04 DEGREES

SET VANE 4 TO     5.02 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD OL   CONSTANT AT A VALUE OF         76.779
CORRECTED FLOW= 82.7100

SURGE MARGIN=    9.9700

EFFICIENCY=    87.2600

*******************************


PRECISE FUNCTION VALUES
  0.82710E+02  0.99700E+01  0.87260E+02
```

```
BEGIN ITERATION NUMBER     4

NOMINAL DESIGN NUMBER =     8

X-VECTOR
  0.23125E+02  0.12843E+02  0.90400E+01  0.50200E+01

FUNCTION VALUES
  0.82710E+02  0.99700E+01  0.87260E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.27535E+00 -0.10000E+01 -0.49622E+00 -0.20002E-01

X-VECTOR
  0.23400E+02  0.11843E+02  0.85438E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.83101E+02  0.85726E+01  0.87614E+02
********************************

SET VANE 1 TO   23.40 DEGREES

SET VANE 2 TO   11.84 DEGREES

SET VANE 3 TO    8.54 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RFMC CONSTANT AT A VALUE OF       5567.500
HOLD OL   CONSTANT AT A VALUE OF         76.779
CORRECTED FLOW= 62.8800

SURGE MARGIN=   10.1000

EFFICIENCY=     87.2000

********************************


PRECISE FUNCTION VALUES
  0.82880E+02  0.10100E+02  0.87200E+02


BEGIN ITERATION NUMBER     5

NOMINAL DESIGN NUMBER =     9

X-VECTOR
  0.23400E+02  0.11843E+02  0.85438E+01  0.50000E+01

FUNCTION VALUES
  0.82880E+02  0.10100E+02  0.87200E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.67228E+00 -0.30000E+01  0.35910E+00  0.48671E+00

X-VECTOR
  0.22728E+02  0.88430E+01  0.89029E+01  0.54367E+01

APPROXIMATE FUNCTION VALUES
```

```
  0.83304E+02  0.85494E+01  0.87775E+02
********************************

 SET VANE 1 TO   22.73 DEGREES

 SET VANE 2 TO    8.84 DEGREES

 SET VANE 3 TO    8.90 DEGREES

 SET VANE 4 TO    5.49 DEGREES

 HOLD RPMC CONSTANT AT A VALUE OF       5567.500
 HOLD OL   CONSTANT AT A VALUE OF         76.779
 CORRECTED FLOW= 83.3600

 SURGE MARGIN=    9.9100

 EFFICIENCY=     87.0000

********************************


 PRECISE FUNCTION VALUES
   0.83360E+02  0.99100E+01  0.87000E+02


 BEGIN ITERATION NUMBER    6

 NOMINAL DESIGN NUMBER =   10

 X-VECTOR
   0.22728E+02  0.88430E+01  0.89029E+01  0.54867E+01

 FUNCTION VALUES
   0.83360E+02  0.99100E+01  0.87000E+02


 RESULTS OF APPROXIMATE OPTIMIZATION

 DELTA-X VECTOR
   0.38795E+00 -0.12499E+01 -0.82012E-01 -0.48670E+00

 X-VECTOR
   0.23116E+02  0.75931E+01  0.88209E+01  0.50000E+01

 APPROXIMATE FUNCTION VALUES
   0.83616E+02  0.85963E+01  0.87463E+02
********************************


 SET VANE 1 TO   23.12 DEGREES

 SET VANE 2 TO    7.59 DEGREES

 SET VANE 3 TO    8.82 DEGREES

 SET VANE 4 TO    5.00 DEGREES


 HOLD RPMC CONSTANT AT A VALUE OF       5567.500
 HOLD OL   CONSTANT AT A VALUE OF         76.779
 CORRECTED FLOW= 83.4800

 SURGE MARGIN=   10.0300

 EFFICIENCY=     86.9200

********************************
```

```
PRECISE FUNCTION VALUES
  0.83480E+02  0.10030E+02  0.86920E+02

BEGIN ITERATION NUMBER    7

NOMINAL DESIGN NUMBER =   11

X-VECTOR
  0.23116E+02  0.75931E+01  0.88209E+01  0.50000E+01

FUNCTION VALUES
  0.83480E+02  0.10030E+02  0.86920E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.24852E+01  0.21607E+01 -0.30000E+01  0.0

X-VECTOR
  0.20631E+02  0.97537E+01  0.58209E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.84424E+02  0.98653E+01  0.86752E+02
*********************************

SET VANE 1 TO   20.63 DEGREES

SET VANE 2 TO    9.75 DEGREES

SET VANE 3 TO    5.82 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD CL   CONSTANT AT A VALUE OF        76.779
CORRECTED FLOW= 84.3100

SURGE MARGIN=   10.0500

EFFICIENCY=     86.8000

PRECISE FUNCTION VALUES
  0.84310E+02  0.10050E+02  0.86800E+02

BEGIN ITERATION NUMBER    8

NOMINAL DESIGN NUMBER =   12

X-VECTOR
  0.20631E+02  0.97537E+01  0.58209E+01  0.50000E+01

FUNCTION VALUES
  0.84310E+02  0.10050E+02  0.86800E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.35567E+00  0.21365E+00 -0.82088E+00  0.53036E-07

X-VECTOR
  0.20986E+02  0.99674E+01  0.50000E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.84331E+02  0.10388E+02  0.86806E+02
*********************************
```

```
SET VANE 1 TO   20.99 DEGREES

SET VANE 2 TO    9.97 DEGREES

SET VANE 3 TO    5.00 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD CL   CONSTANT AT A VALUE OF        76.779
CORRECTED FLOW= 84.3100

SURGE MARGIN=   10.1400

EFFICIENCY=     86.7800

********************************


PRECISE FUNCTION VALUES
  0.84310E+02  0.10140E+02  0.86780E+02


BEGIN ITERATION NUMBER    9

NOMINAL DESIGN NUMBER =   13

X-VECTOR
  0.20986E+02  0.99674E+01  0.50000E+01  0.50000E+01

FUNCTION VALUES
  0.84310E+02  0.10140E+02  0.86780E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.90549E+00  0.34120E+00  0.85419E+00  0.12793E-05

X-VECTOR
  0.20081E+02  0.10309E+02  0.58542E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.84344E+02  0.98981E+01  0.86785E+02
********************************

SET VANE 1 TO   20.08 DEGREES

SET VANE 2 TO   10.31 DEGREES

SET VANE 3 TO    5.85 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD CL   CONSTANT AT A VALUE OF        76.779
CORRECTED FLOW= 84.3900

SURGE MARGIN=   10.1900

EFFICIENCY=     86.8100

********************************


PRECISE FUNCTION VALUES
  0.84390E+02  0.10190E+02  0.86810E+02
```

```
FINAL RESULT OF APPROXIMATE OPTIMIZATION

NOMINAL DESIGN NUMBER =    14

X-VECTOR
  0.20081E+02  0.10309E+02  0.58542E+01  0.50000E+01

FUNCTION VALUES
  0.84390E+02  0.10190E+02  0.86810E+02

RESULTS OF APPROXIMATE ANALYSIS/OPTIMIZATION

TITLE
************************************************

GLOBAL LOCATIONS OF X-VARIABLES
    1    2    3    4

GLOBAL LOCATIONS OF FUNCTIONS, F(X)
    8    6    7

APPROXIMATION IS BASED ON   14 DESIGNS

NOMINAL DESIGN IS DESIGN NUMBER   14

VALUES OF X-VARIABLES
   0.2008E+02   0.1031E+02   0.5854E+01   0.5000E+01

VALUES OF FUNCTIONS, F(X)
   0.8439E+02   0.1019E+02   0.8681E+02

COEFFICIENTS OF TAYLOR SERIES EXPANSION

PARAMETER    1 = GLOBAL VARIABLE    8

LINEAR TERMS, DEL F
  -0.2423E+00  -0.1381E+00  -0.1230E+00  -0.1432E+00

NON-LINEAR TERMS, H, BEGINING WITH DIAGONAL ELEMENT

ROW    1
  -0.2481E-01

ROW    2
  -0.7663E-02

ROW    3
  -0.1002E-01

ROW    4
  -0.1176E-02

PARAMETER    2 = GLOBAL VARIABLE    6

LINEAR TERMS, DEL F
  -0.2136E-01   0.1367E-01   0.1433E-01  -0.9647E-02

NON-LINEAR TERMS, H, BEGINING WITH DIAGONAL ELEMENT
```

ROW 1
-0.2248E-01

ROW 2
-0.5767E-02

ROW 3
-0.1213E-01

ROW 4
-0.1417E-01

PARAMETER 3 = GLOBAL VARIABLE 7

LINEAR TERMS, DEL F
0.7552E-01 0.6521E-01 0.7303E-01 0.2221E-01

NON-LINEAR TERMS, H, BEGINING WITH DIAGONAL ELEMENT

ROW 1
-0.2104E-01

ROW 2
-0.4665E-02

ROW 3
-0.1203E-01

ROW 4
-0.9592E-02

OPTIMIZATION RESULTS

OBJECTIVE FUNCTION
GLOBAL LOCATION 8 FUNCTION VALUE 0.84390E+02

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	1	1	0.10000E+02	0.20081E+02	0.35000E+02
2	2	2	0.50000E+01	0.10309E+02	0.25000E+02
3	3	3	0.50000E+01	0.58542E+01	0.25000E+02
4	4	4	0.50000E+01	0.50000E+01	0.25000E+02

DESIGN CONSTRAINTS

ID	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	6	0.85000E+01	0.10190E+02	0.10000E+03
3	7	0.87000E+02	0.86810E+02	0.10000E+04

********* FINAL SOLUTION VALUES ********

VANE ANGLE FOR VANE 1 IS 20.08 DEGREES

VANE ANGLE FOR VANE 2 IS 10.31 DEGREES

VANE ANGLE FOR VANE 3 IS 5.85 DEGREES

VANE ANGLE FOR VANE 4 IS 5.00 DEGREES

```
CORRECTED FLOW= 84.3900

EFFICIENCY=     86.8100

SURGE MARGIN=   10.1900

RPMC WAS HELD CONSTANT AT        5567.50
OL   WAS HELD CONSTANT AT          76.78

PROGRAM CALLS TO ANALIZ

    ICALC   CALLS
      1       1
      2      14
      3       1
```

```
                    STATOR VANE OPTIMIZER
                    *********************
    PROTOTYPE SOFTWARE CAPABLE OF GUIDING THE OPTIMIZATION OF

    STATOR VANE AND BLEED SETTINGS IN A MULTI-STAGE COMPRESSOR

    PREPARED FOR THE AIR FORCE AERO PROPULSION LABORATORY

    UNDER CONTRACT F33615-79-C-2013

    BY: PRATT & WHITNEY AIRCRAFT GROUP
        GOVERNMENT PRODUCTS DIVISION


    PLEASE HIT RETURN TO VIEW OPTIMIZATION GOAL MENU
 -------------------------------------------------
              I OPTIMIZATION CONDITIONS I CONSTRAINTS I
 NO I  GOAL   I RPMC  WC  PR  DVS  O.L. I S.M. I EFF  I
 ---+---------+-------------------------+------+------
  1 I   EFF   I  X    -   -    X    -   I  -   I  -   I
  2 I   EFF   I  X    -   -    -    X   I  -   I  -   I
  3 I   EFF   I  -    X   X    -    -   I  -   I  -   I
  4 I   EFF   I  X    -   -    X    -   I MIN  I  -   I
  5 I   EFF   I  X    -   -    -    X   I MIN  I  -   I
  6 I   EFF   I  -    X   X    -    -   I MIN  I  -   I
  7 I  S.M.   I  X    -   -    X    -   I  -   I  -   I
  8 I  S.M.   I  X    -   -    -    X   I  -   I  -   I
  9 I  S.M.   I  -    X   X    -    -   I  -   I  -   I
 10 I  S.M.   I  X    -   -    X    -   I  -   I MIN  I
 11 I  S.M.   I  X    -   -    -    X   I  -   I MIN  I
 12 I  S.M.   I  -    X   X    -    -   I  -   I MIN  I
 13 I SM/BLD  I  X    X   -    -    -   I  -   I  -   I
 14 I MAX WC  I  X    -   -    -    X   I MIN  I MIN  I
 15 I MIN WC  I  X    -   -    -    X   I MIN  I MIN  I
 16 I   PR    I  X    X   -    -    -   I MIN  I MIN  I
 17 I   PR    I  X    -   -    -    X   I MIN  I MIN  I
 YOU HAVE SELECTED TO MINIMIZE CORRECTED FLOW HOLDING

 CORRECTED SPEED (RPMC) AND OPERATING LINE (OL) CONSTANT

 WHILE CONSTRAINING SURGE MARGIN AND EFFICIENCY TO MINIMUM VALUES
 HOLD RPMC CONSTANT AT    5567.500
 HOLD OL   CONSTANT AT      76.779
 OPTIMIZING 4 VANE ANGLE(S)
 LOWER BOUND FOR VANE 1 IS     10.000
 DO YOU AGREE? (Y/N)
 LOWER BOUND FOR VANE 2 IS      5.000
 DO YOU AGREE? (Y/N)
 LOWER BOUND FOR VANE 3 IS      5.000
 DO YOU AGREE? (Y/N)
 LOWER BOUND FOR VANE 4 IS      5.000
 DO YOU AGREE? (Y/N)
 UPPER BOUND FOR VANE 1 IS     35.000
 DO YOU AGREE? (Y/N)
 UPPER BOUND FOR VANE 2 IS     25.000
 DO YOU AGREE? (Y/N)

 UPPER BOUND FOR VANE 3 IS     25.000
 DO YOU AGREE? (Y/N)
 UPPER BOUND FOR VANE 4 IS     25.000
 DO YOU AGREE? (Y/N)
 LOWER BOUND VALUE FOR SM   IS       8.500
 UPPER BOUND VALUE FOR SM   IS     100.000
 LOWER BOUND VALUE FOR EFF  IS      87.000
 UPPER BOUND VALUE FOR EFF  IS    1000.000
 INCREMENTAL VANE ANGLE VALUE FOR INITIAL VANE SETTING IS    -2.00
```

TITLE:
****

CONTROL PARAMETERS;
CALCULATION CONTROL, NCALC = 6
NUMBER OF GLOBAL DESIGN VARIABLES, NDV = 4
NUMBER OF SENSITIVITY VARIABLES, NSV = 0
NUMBER OF FUNCTIONS IN TWO-SPACE, N2VAR = 0
NUMBER OF APPROXIMATING VAR. NXAPRX = 4
INPUT INFORMATION PRINT CODE, IPNPUT = 1
DEBUG PRINT CODE, IPDBG = 0

CALCULATION CONTROL, NCALC

VALUE	MEANING
1	SINGLE ANALYSIS
2	OPTIMIZATION
3	SENSITIVITY
4	TWO-VARIABLE FUNCTION SPACE
5	OPTIMUM SENSITIVITY
6	APPROXIMATE OPTIMIZATION

* * OPTIMIZATION INFORMATION

GLOBAL VARIABLE NUMBER OF OBJECTIVE = 8
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION) = -0.1000E+01

CONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVER-RIDE)

IPRINT	ITMAX	ICNDIR	NSCAL	ITRM	LINOBJ	NACMX1	NFDG
5	20	5	0	3	0	10	0

FDCH	FDCHM	CT	CTMIN
0.10000E-01	0.10000E-02	-0.50000E-01	0.40000E-02

CTL	CTLMIN	THETA	PHI
-0.10000E-01	0.10000E-02	0.10000E+01	0.0

DELFUN	DABFUN	ALPHAX	ABOBJ1
0.10000E-02	0.0	0.10000E+00	0.10000E+00

DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT

D. V. NO.	LOWER BOUND	UPPER BOUND	INITIAL VALUE	SCALE
1	0.10000E+02	0.35000E+02	0.27000E+02	0.0
2	0.50000E+01	0.25000E+02	0.16000E+02	0.0
3	0.50000E+01	0.25000E+02	0.13000E+02	0.0
4	0.50000E+01	0.25000E+02	0.90000E+01	0.0

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	MULTIPLYING FACTOR
1	1	1	0.10000E+01

```
2       2          2        0.10000E+01
3       3          3        0.10000E+01
4       4          4        0.10000E+01
```

CONSTRAINT INFORMATION

THERE ARE 2 CONSTRAINT SETS

ID	GLOBAL VAR. 1	GLOBAL VAR. 2	LINEAR ID	LOWER BOUND	NORMALIZATION FACTOR	UPPER BOUND	NORMALIZATION FACTOR
1	6	6	0	0.85000E+01	0.85000E+01	0.10000E+03	0.10000E+03
3	7	7	0	0.87000E+02	0.87000E+02	0.10000E+04	0.10000E+04

TOTAL NUMBER OF CONSTRAINED PARAMETERS = 2

* * APPROXIMATE ANALYSIS/OPTIMIZATION INFORMATION

```
NUMBER OF FUNCTIONS APPROXIMATED, NF =    0
NUMBER OF INPUT X-VECTORS,       NPS =    5
NUMBER OF INPUT X-F PAIRS,      NPFS =    0
X-VECTOR FROM ANALIZ,            NPA =    0
NOMINAL DESIGN,                 INOM =    0
READ UNIT FOR X-VECTORS,       ISCRX =    5
READ UNIT FOR X-F PAIRS,      ISCRXF =    5
PRINT CONTROL,                IPAPRX =    1

MINIMUM APPROXIMATING CYCLES,   KMIN =    5
MAXIMUM APPROXIMATING CYCLES,   KMAX =   17
MAXIMUM DESIGNS USED IN FIT,   NPMAX =   28
NOMINAL DESIGN PARAMETER,       JNOM =   28
X-LOCATION INPUT PARAMETER,   INXLOC =    0
F-LOCATION INPUT PARAMETER,   INFLOC =    0
TAYLER SERIES I.D. CODE,      MAXTRM =    2
```

DELTA-X BOUNDS FOR APPROXIMATE OPTIMIZATION
0.2000E+01 0.2000E+01 0.2000E+01 0.2000E+01

```
MULTIPLIER ON DELX,           XFACT1 =  0.1500E+01
MULTIPLIER ON DELX,           YFACT2 =  0.2000E+01
```

GLOBAL LOCATIONS OF X-VARIABLES
1 2 3 4

GLOBAL LOCATIONS OF FUNCTIONS
8 6 7

X-VECTORS INPUT FROM UNIT 5

NUMBER 1 DESIGN 1
0.2900E+02 0.1800E+02 0.1500E+02 0.1100E+02

NUMBER 2 DESIGN 2

```
0.2700E+02  0.1800E+02  0.1500E+02  0.1100E+02

NUMBER    3     DESIGN    3
0.2700E+02  0.1600E+02  0.1500E+02  0.1100E+02

NUMBER    4     DESIGN    4
0.2700E+02  0.1600E+02  0.1300E+02  0.1100E+02

NUMBER    5     DESIGN    5
0.2700E+02  0.1600E+02  0.1300E+02  0.9000E+01


* * ESTIMATED DATA STORAGE REQUIREMENTS

             REAL                          INTEGER
INPUT  EXECUTION  AVAILABLE      INPUT  EXECUTION  AVAILABLE
  41       355       5000          30        78       1000
*********************************

SET VANE 1 TO   29.00 DEGREES

SET VANE 2 TO   18.00 DEGREES

SET VANE 3 TO   15.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RFMC CONSTANT AT A VALUE OF       5567.500
HOLD OL    CONSTANT AT A VALUE OF        76.779
CORRECTED FLOW= 77.5300

SURGE MARGIN=    8.3600

EFFICIENCY=      87.1800

*********************************

*********************************

SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   18.00 DEGREES

SET VANE 3 TO   15.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RFMC CONSTANT AT A VALUE OF       5567.500
HOLD OL    CONSTANT AT A VALUE OF        76.779
CORRECTED FLOW= 78.4200

SURGE MARGIN=    8.8300
```

EFFICIENCY=   87.3100

****

****

SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   16.00 DEGREES

SET VANE 3 TO   15.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF   5567.500
HOLD OL   CONSTANT AT A VALUE OF   76.779
CORRECTED FLOW= 78.7800

SURGE MARGIN=   8.8300

EFFICIENCY=   87.2500

****

****

SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   16.00 DEGREES

SET VANE 3 TO   13.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF   5567.500
HOLD OL   CONSTANT AT A VALUE OF   76.779
CORRECTED FLOW= 79.1900

SURGE MARGIN=   8.9700

EFFICIENCY=   87.3000

****

****

SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   16.00 DEGREES

SET VANE 3 TO   13.00 DEGREES

SET VANE 4 TO   9.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF   5567.500
HOLD OL   CONSTANT AT A VALUE OF   76.779
CORRECTED FLOW= 79.4900

SURGE MARGIN=   9.2100

EFFICIENCY=   87.3300

****

```
APPROXIMATE OPTIMIZATION ITERATION HISTORY

APPROXIMATING FUNCTION    1 IS THE OBJECTIVE

APPROXIMATING FUNCTIONS ASSOCIATED WITH CONSTRAINTS
    2    3

DESIGN VARIABLE NUMBERS ASSOCIATED WITH APPROXIMATING VARIABLES
    1    2    3    4


BEGIN ITERATION NUMBER    1

NOMINAL DESIGN NUMBER =    2

X-VECTOR
  0.27000E+02  0.18000E+02  0.15000E+02  0.11000E+02

FUNCTION VALUES
  0.78420E+02  0.88300E+01  0.87310E+02


RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.48537E+00  0.20000E+01  0.20000E+01  0.20000E+01

X-VECTOR
  0.26515E+02  0.20000E+02  0.17000E+02  0.13000E+02

APPROXIMATE FUNCTION VALUES
  0.77566E+02  0.85641E+01  0.87322E+02
********************************


SET VANE 1 TO   26.51 DEGREES

SET VANE 2 TO   20.00 DEGREES

SET VANE 3 TO   17.00 DEGREES

SET VANE 4 TO   13.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD OL   CONSTANT AT A VALUE OF         76.779
CORRECTED FLOW= 77.2500

SURGE MARGIN=    8.2100

EFFICIENCY=     86.9400

********************************


PRECISE FUNCTION VALUES
  0.77250E+02  0.82100E+01  0.86940E+02
```

```
BEGIN ITERATION NUMBER     2

NOMINAL DESIGN NUMBER =     6

X-VECTOR
  0.26515E+02  0.20000E+02  0.17000E+02  0.13000E+02

FUNCTION VALUES
  0.77250E+02  0.82100E+01  0.86940E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.17665E+01  0.20000E+01  0.20000E+01 -0.18405E+01

X-VECTOR
  0.28281E+02  0.22000E+02  0.19000E+02  0.11159E+02

APPROXIMATE FUNCTION VALUES
  0.76527E+02  0.85000E+01  0.87535E+02
********************************

SET VANE 1 TO   28.28 DEGREES

SET VANE 2 TO   22.00 DEGREES

SET VANE 3 TO   19.00 DEGREES

SET VANE 4 TO   11.16 DEGREES

HOLD RFNC CONSTANT AT A VALUE OF      5567.500
HOLD CL   CONSTANT AT A VALUE OF        76.779
CORRECTED FLOW= 75.8800

SURGE MARGIN=    7.5700

EFFICIENCY=     86.6700

********************************

PRECISE FUNCTION VALUES
  0.75830E+02  0.75700E+01  0.86670E+02

BEGIN ITERATION NUMBER     3

NOMINAL DESIGN NUMBER =     7

X-VECTOR
  0.28281E+02  0.22000E+02  0.19000E+02  0.11159E+02

FUNCTION VALUES
  0.75830E+02  0.75700E+01  0.86670E+02
```

```
RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.83365E+00 -0.29508E+01  0.20000E+01 -0.20000E+01

X-VECTOR
  0.27447E+02  0.19049E+02  0.21000E+02  0.91595E+01

APPROXIMATE FUNCTION VALUES
  0.77092E+02  0.84882E+01  0.87185E+02
********************************

SET VANE 1 TO   27.45 DEGREES

SET VANE 2 TO   19.05 DEGREES

SET VANE 3 TO   21.00 DEGREES

SET VANE 4 TO    9.16 DEGREES

HOLD RFMC CONSTANT AT A VALUE OF      5567.500
HOLD OL   CONSTANT AT A VALUE OF        76.779
CORRECTED FLOW= 76.2900

SURGE MARGIN=     7.5500

EFFICIENCY=      86.1500

********************************


PRECISE FUNCTION VALUES
  0.76290E+02  0.75500E+01  0.86150E+02


BEGIN ITERATION NUMBER     4

NOMINAL DESIGN NUMBER =     8

X-VECTOR
  0.27447E+02  0.19049E+02  0.21000E+02  0.91595E+01

FUNCTION VALUES
  0.76290E+02  0.75500E+01  0.86150E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.31427E-01  0.30000E+01 -0.30000E+01 -0.20000E+01

X-VECTOR
  0.27479E+02  0.22049E+02  0.18000E+02  0.71595E+01

APPROXIMATE FUNCTION VALUES
```

```
     0.77170E+02  0.84750E+01  0.86989E+02
*********************************

   SET VANE 1 TO   27.48 DEGREES

   SET VANE 2 TO   22.05 DEGREES

   SET VANE 3 TO   18.00 DEGREES

   SET VANE 4 TO    7.16 DEGREES

   HOLD RPMC CONSTANT AT A VALUE OF       5567.500
   HOLD OL   CONSTANT AT A VALUE OF         76.779
   CORRECTED FLOW= 76.8800

   SURGE MARGIN=    8.0200

   EFFICIENCY=     86.8000

*********************************

   PRECISE FUNCTION VALUES
     0.76880E+02  0.80200E+01  0.86800E+02

   BEGIN ITERATION NUMBER     5

   NOMINAL DESIGN NUMBER =    9

   X-VECTOR
     0.27479E+02  0.22049E+02  0.18000E+02  0.71595E+01

   FUNCTION VALUES
     0.76880E+02  0.80200E+01  0.86800E+02

   RESULTS OF APPROXIMATE OPTIMIZATION

   DELTA-X VECTOR
    -0.63346E+00  0.29508E+01  0.12337E+01  0.30000E+01

   X-VECTOR
     0.26840E+02  0.25000E+02  0.19234E+02  0.10159E+02

   APPROXIMATE FUNCTION VALUES
     0.76410E+02  0.85000E+01  0.86861E+02
*********************************

   SET VANE 1 TO   26.84 DEGREES

   SET VANE 2 TO   25.00 DEGREES

   SET VANE 3 TO   19.23 DEGREES

   SET VANE 4 TO   10.16 DEGREES
```

```
HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD OL   CONSTANT AT A VALUE OF        76.779
CORRECTED FLOW= 75.1800

SURGE MARGIN=    7.0000

EFFICIENCY=     86.1100

********************************


PRECISE FUNCTION VALUES
  0.75180E+02  0.70000E+01  0.86110E+02


BEGIN ITERATION NUMBER    6

NOMINAL DESIGN NUMBER =   10

X-VECTOR
  0.26840E+02  0.25000E+02  0.19234E+02  0.10159E+02

FUNCTION VALUES
  0.75180E+02  0.70000E+01  0.86110E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.81091E+00 -0.30000E+01 -0.30000E+01 -0.14534E+01

X-VECTOR
  0.27651E+02  0.22000E+02  0.16234E+02  0.87060E+01

APPROXIMATE FUNCTION VALUES
  0.77244E+02  0.83505E+01  0.87146E+02
********************************

SET VANE 1 TO   27.65 DEGREES

SET VANE 2 TO   22.00 DEGREES

SET VANE 3 TO   16.23 DEGREES

SET VANE 4 TO    8.71 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD OL   CONSTANT AT A VALUE OF        76.779
CORRECTED FLOW= 77.1800

SURGE MARGIN=    8.2300

EFFICIENCY=     87.0700

********************************
PRECISE FUNCTION VALUES
  0.77180E+02  0.82300E+01  0.87070E+02


BEGIN ITERATION NUMBER    7

NOMINAL DESIGN NUMBER =   11

X-VECTOR
  0.27651E+02  0.22000E+02  0.16234E+02  0.87060E+01

FUNCTION VALUES
  0.77180E+02  0.82300E+01  0.87070E+02
```

```
RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.62297E-01 -0.86176E+00 -0.83577E+00 -0.12166E+00

X-VECTOR
   0.27589E+02  0.21138E+02  0.15398E+02  0.85843E+01

APPROXIMATE FUNCTION VALUES
   0.77682E+02  0.84913E+01  0.87205E+02
*********************************

SET VANE 1 TO   27.59 DEGREES

SET VANE 2 TO   21.14 DEGREES

SET VANE 3 TO   15.40 DEGREES

SET VANE 4 TO    8.58 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD OL   CONSTANT AT A VALUE OF        76.779
CORRECTED FLOW= 77.6800

SURGE MARGIN=    8.4500

EFFICIENCY=     87.2200

*********************************


PRECISE FUNCTION VALUES
   0.77680E+02  0.84500E+01  0.87220E+02


BEGIN ITERATION NUMBER    8

NOMINAL DESIGN NUMBER =   12


X-VECTOR
   0.27589E+02  0.21138E+02  0.15398E+02  0.85843E+01

FUNCTION VALUES
   0.77680E+02  0.84500E+01  0.87220E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
   0.24845E+00 -0.36500E+00 -0.20615E+00 -0.47718E-01

X-VECTOR
   0.27838E+02  0.20773E+02  0.15192E+02  0.85366E+01

APPROXIMATE FUNCTION VALUES
   0.77766E+02  0.84999E+01  0.87271E+02
*********************************

SET VANE 1 TO   27.84 DEGREES

SET VANE 2 TO   20.77 DEGREES

SET VANE 3 TO   15.19 DEGREES

SET VANE 4 TO    8.54 DEGREES
```

```
HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD OL   CONSTANT AT A VALUE OF         76.779
CORRECTED FLOW= 77.7300

SURGE MARGIN=    8.4800

EFFICIENCY=     87.2300

*********************************


PRECISE FUNCTION VALUES
  0.77730E+02  0.84800E+01  0.87230E+02


BEGIN ITERATION NUMBER     9

NOMINAL DESIGN NUMBER =    13

X-VECTOR
  0.27838E+02  0.20773E+02  0.15192E+02  0.85366E+01

FUNCTION VALUES
  0.77730E+02  0.84800E+01  0.87230E+02


RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.87768E-01 -0.85184E+00  0.52813E+00  0.10000E+01

X-VECTOR
  0.27925E+02  0.19921E+02  0.15720E+02  0.95366E+01

APPROXIMATE FUNCTION VALUES
  0.77677E+02  0.84683E+01  0.87235E+02
*********************************


SET VANE 1 TO    27.93 DEGREES

SET VANE 2 TO    19.92 DEGREES

SET VANE 3 TO    15.72 DEGREES

SET VANE 4 TO     9.54 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD OL   CONSTANT AT A VALUE OF         76.779
CORRECTED FLOW= 77.6500

SURGE MARGIN=    8.4700

EFFICIENCY=     87.2000

*********************************


PRECISE FUNCTION VALUES
  0.77650E+02  0.84700E+01  0.87200E+02


BEGIN ITERATION NUMBER    10

NOMINAL DESIGN NUMBER =    14
```

```
X-VECTOR
  0.27925E+02  0.19921E+02  0.15720E+02  0.95366E+01

FUNCTION VALUES
  0.77650E+02  0.84700E+01  0.87200E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.23842E-06 -0.28610E-05  0.28610E-05 -0.28610E-05

X-VECTOR
  0.27925E+02  0.19921E+02  0.15720E+02  0.95366E+01

APPROXIMATE FUNCTION VALUES
  0.77650E+02  0.84700E+01  0.87200E+02
**********************************

SET VANE 1 TO   27.93 DEGREES

SET VANE 2 TO   19.92 DEGREES

SET VANE 3 TO   15.72 DEGREES

SET VANE 4 TO    9.54 DEGREES

HOLD RFMC CONSTANT AT A VALUE OF       5567.500
HOLD OL    CONSTANT AT A VALUE OF         76.779
CORRECTED FLOW= 77.6500

SURGE MARGIN=    8.4700

EFFICIENCY=     37.2000

**********************************

PRECISE FUNCTION VALUES
  0.77650E+02  0.84700E+01  0.87200E+02


BEGIN ITERATION NUMBER   11

NOMINAL DESIGN NUMBER =   15

X-VECTOR
  0.27925E+02  0.19921E+02  0.15720E+02  0.95366E+01

FUNCTION VALUES
  0.77650E+02  0.84700E+01  0.87200E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.11921E-06 -0.17881E-06  0.0          -0.17881E-06

X-VECTOR
  0.27925E+02  0.19921E+02  0.15720E+02  0.95366E+01

APPROXIMATE FUNCTION VALUES
  0.77650E+02  0.84700E+01  0.87200E+02

TWO CONSECUTIVE APPROXIMATE OPTIMIZATIONS HAVE PRODUCED THE SAME DESIGN

OPTIMIZATION TERMINATED
```

FINAL RESULT OF APPROXIMATE OPTIMIZATION

NOMINAL DESIGN NUMBER = 15

X-VECTOR
0.27925E+02 0.19921E+02 0.15720E+02 0.95366E+01

FUNCTION VALUES
0.77650E+02 0.84700E+01 0.87200E+02

RESULTS OF APPROXIMATE ANALYSIS/OPTIMIZATION

TITLE
****

GLOBAL LOCATIONS OF X-VARIABLES
1 2 3 4

GLOBAL LOCATIONS OF FUNCTIONS, F(X)
8 6 7

APPROXIMATION IS BASED ON 15 DESIGNS

NOMINAL DESIGN IS DESIGN NUMBER 15

VALUES OF X-VARIABLES
0.2793E+02 0.1992E+02 0.1572E+02 0.9537E+01

VALUES OF FUNCTIONS, F(X)
0.7765E+02 0.8470E+01 0.8720E+02

COEFFICIENTS OF TAYLOR SERIES EXPANSION

PARAMETER 1 = GLOBAL VARIABLE 8

LINEAR TERMS, DEL F
-0.3840E+00 -0.2487E+00 -0.2766E+00 -0.1046E+00

NON-LINEAR TERMS, H, BEGINING WITH DIAGONAL ELEMENT

ROW 1
-0.4113E+00

ROW 2
-0.1495E-01

ROW 3
-0.1973E-01

ROW 4
0.3927E-01

PARAMETER 2 = GLOBAL VARIABLE 6

LINEAR TERMS, DEL F
-0.1750E+00 -0.1113E+00 -0.1378E+00 -0.4375E-01

NON-LINEAR TERMS, H, BEGINING WITH DIAGONAL ELEMENT

ROW 1
-0.2323E+00

ROW 2
-0.2114E-01

ROW 3
-0.2346E-01

ROW 4
0.1625E-01

PARAMETER 3 = GLOBAL VARIABLE 7

LINEAR TERMS, DEL F
-0.9254E-02 -0.3304E-01 -0.1099E+00 0.9230E-02

NON-LINEAR TERMS, H, BEGINING WITH DIAGONAL ELEMENT

ROW 1
-0.2990E+00

ROW 2
-0.1134E-01

ROW 3
-0.3256E-01

ROW 4
0.3116E-01

OPTIMIZATION RESULTS

OBJECTIVE FUNCTION
GLOBAL LOCATION 8 FUNCTION VALUE 0.77650E+02

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	1	1	0.10000E+02	0.27925E+02	0.35000E+02
2	2	2	0.50000E+01	0.19921E+02	0.25000E+02
3	3	3	0.50000E+01	0.15720E+02	0.25000E+02
4	4	4	0.50000E+01	0.95366E+01	0.25000E+02

DESIGN CONSTRAINTS

ID	GLOBAL VAR. NO.	LOWER BOUND	VALUE	UPPER BOUND
1	6	0.85000E+01	0.84700E+01	0.10000E+03
3	7	0.87000E+02	0.87200E+02	0.10000E+04

********* FINAL SOLUTION VALUES ********

VANE ANGLE FOR VANE 1 IS 27.93 DEGREES

VANE ANGLE FOR VANE 2 IS 19.92 DEGREES

VANE ANGLE FOR VANE 3 IS 15.72 DEGREES

VANE ANGLE FOR VANE 4 IS 9.54 DEGREES

CORRECTED FLOW= 77.6500

```
EFFICIENCY=      87.2000

SURGE MARGIN=    8.4700

RPMC WAS HELD CONSTANT AT        5567.50
OL   WAS HELD CONSTANT AT          76.78

PROGRAM CALLS TO ANALIZ

   ICALC   CALLS
     1       1
     2      15
     3       1
```

```
                    STATOR VANE OPTIMIZER
                    *********************
        PROTOTYPE SOFTWARE CAPABLE OF GUIDING THE OPTIMIZATION OF

        STATOR VANE AND BLEED SETTINGS IN A MULTI-STAGE COMPRESSOR

        PREPARED FOR THE AIR FORCE AERO PROPULSION LABORATORY

        UNDER CONTRACT F33615-79-C-2013

        BY: PRATT & WHITNEY AIRCRAFT GROUP
            GOVERNMENT PRODUCTS DIVISION


        PLEASE HIT RETURN TO VIEW OPTIMIZATION GOAL MENU
   -----------------------------------------------------
                I OPTIMIZATION CONDITIONS I CONSTRAINTS I
   NO I  GOAL   I RPMC  WC  PR  DVS  O.L. I S.M. I EFF  I
   ---+---------+-------------------------+------+------
    1 I   EFF   I X     -   -    X    -   I  -   I  -   I
    2 I   EFF   I X     -   -    -    X   I  -   I  -   I
    3 I   EFF   I -     X   X    -    -   I  -   I  -   I
    4 I   EFF   I X     -   -    X    -   I MIN  I  -   I
    5 I   EFF   I X     -   -    -    X   I MIN  I  -   I
    6 I   EFF   I -     X   X    -    -   I MIN  I  -   I
    7 I  S.M.   I X     -   -    X    -   I  -   I  -   I
    8 I  S.M.   I X     -   -    -    X   I  -   I  -   I
    9 I  S.M.   I -     X   X    -    -   I  -   I  -   I
   10 I  S.M.   I X     -   -    X    -   I  -   I MIN  I
   11 I  S.M.   I X     -   -    -    X   I  -   I MIN  I
   12 I  S.M.   I -     X   X    -    -   I  -   I MIN  I
   13 I SM/BLD  I X     X   -    -    -   I  -   I  -   I
   14 I MAX WC  I X     -   -    -    X   I MIN  I MIN  I
   15 I MIN WC  I X     -   -    -    X   I MIN  I MIN  I
   16 I   PR    I X     X   -    -    -   I MIN  I MIN  I
   17 I   PR    I X     -   -    -    X   I MIN  I MIN  I
   YOU HAVE SELECTED TO OPTIMIZE PRESSURE RATIO HOLDING

   CORRECTED SPEED (RPMC) AND OPERATING LINE (OL) CONSTANT

   WHILE CONSTRAINING SURGE MARGIN AND EFFICIENCY TO MINIMUM VALUES
   HOLD RPMC CONSTANT AT    5567.500
   HOLD OL   CONSTANT AT      76.779
   OPTIMIZING 4 VANE ANGLE(S)
   LOWER BOUND FOR VANE 1 IS    10.000
   DO YOU AGREE? (Y/N)
   LOWER BOUND FOR VANE 2 IS     5.000
   DO YOU AGREE? (Y/N)
   LOWER BOUND FOR VANE 3 IS     5.000
   DO YOU AGREE? (Y/N)
   LOWER BOUND FOR VANE 4 IS     5.000
   DO YOU AGREE? (Y/N)
   UPPER BOUND FOR VANE 1 IS    35.000
   DO YOU AGREE? (Y/N)
   UPPER BOUND FOR VANE 2 IS    25.000
   DO YOU AGREE? (Y/N)

   UPPER BOUND FOR VANE 3 IS    25.000
   DO YOU AGREE? (Y/N)
   UPPER BOUND FOR VANE 4 IS    25.000
   DO YOU AGREE? (Y/N)
   LOWER BOUND VALUE FOR SM   IS       8.500
   UPPER BOUND VALUE FOR SM   IS     100.000
   LOWER BOUND VALUE FOR EFF  IS      87.000
   UPPER BOUND VALUE FOR EFF  IS    1000.000
   INCREMENTAL VANE ANGLE VALUE FOR INITIAL VANE SETTING IS     -2.00
```

TITLE:
****

CONTROL PARAMETERS;

CALCULATION CONTROL,	NCALC =	6
NUMBER OF GLOBAL DESIGN VARIABLES,	NDV =	4
NUMBER OF SENSITIVITY VARIABLES,	NSV =	0
NUMBER OF FUNCTIONS IN TWO-SPACE,	N2VAR =	0
NUMBER OF APPROXIMATING VAR.	NXAPRX =	4
INPUT INFORMATION PRINT CODE,	IPNPUT =	1
DEBUG PRINT CODE,	IPDBG =	0

CALCULATION CONTROL, NCALC

VALUE	MEANING
1	SINGLE ANALYSIS
2	OPTIMIZATION
3	SENSITIVITY
4	TWO-VARIABLE FUNCTION SPACE
5	OPTIMUM SENSITIVITY
6	APPROXIMATE OPTIMIZATION

* * OPTIMIZATION INFORMATION

GLOBAL VARIABLE NUMBER OF OBJECTIVE = 9
MULTIPLIER (NEGATIVE INDICATES MINIMIZATION) = 0.1000E+01

CONMIN PARAMETERS (IF ZERO, CONMIN DEFAULT WILL OVER-RIDE)

IPRINT	ITMAX	ICNDIR	NSCAL	ITRM	LINOBJ	NACMX1	NFDG
5	20	5	0	3	0	10	0

FDCH	FDCHM	CT	CTMIN
0.10000E-01	0.10000E-02	-0.50000E-01	0.40000E-02
CTL	**CTLMIN**	**THETA**	**PHI**
-0.10000E-01	0.10000E-02	0.10000E+01	0.0
DELFUN	**DABFUN**	**ALPHAX**	**ABOBJ1**
0.10000E-02	0.0	0.10000E+00	0.10000E+00

DESIGN VARIABLE INFORMATION
NON-ZERO INITIAL VALUE WILL OVER-RIDE MODULE INPUT

D. V. NO.	LOWER BOUND	UPPER BOUND	INITIAL VALUE	SCALE
1	0.10000E+02	0.35000E+02	0.27000E+02	0.0
2	0.50000E+01	0.25000E+02	0.16000E+02	0.0
3	0.50000E+01	0.25000E+02	0.13000E+02	0.0
4	0.50000E+01	0.25000E+02	0.90000E+01	0.0

DESIGN VARIABLES

ID	D. V. NO.	GLOBAL VAR. NO.	MULTIPLYING FACTOR
1	1	1	0.10000E+01

```
   2      2          2        0.10000E+01
   3      3          3        0.10000E+01
   4      4          4        0.10000E+01
```

CONSTRAINT INFORMATION

THERE ARE 2 CONSTRAINT SETS

ID	GLOBAL VAR. 1	GLOBAL VAR. 2	LINEAR ID	LOWER BOUND	NORMALIZATION FACTOR	UPPER BOUND	NORMALIZATION FACTOR
1	6	6	0	0.85000E+01	0.85000E+01	0.10000E+03	0.10000E+03
3	7	7	0	0.87000E+02	0.87000E+02	0.10000E+04	0.10000E+04

TOTAL NUMBER OF CONSTRAINED PARAMETERS = 2

* * APPROXIMATE ANALYSIS/OPTIMIZATION INFORMATION

```
NUMBER OF FUNCTIONS APPROXIMATED, NF =    0
NUMBER OF INPUT X-VECTORS,        NFS =   5
NUMBER OF INPUT X-F PAIRS,       NPFS =   0
X-VECTOR FROM ANALIZ,             NPA =   0
NOMINAL DESIGN,                  INOM =   0
READ UNIT FOR X-VECTORS,        ISCRX =   5
READ UNIT FOR X-F PAIRS,       ISCRXF =   5
PRINT CONTROL,                 IPAPRX =   1

MINIMUM APPROXIMATING CYCLES,    KMIN =   5
MAXIMUM APPROXIMATING CYCLES,    KMAX =  17
MAXIMUM DESIGNS USED IN FIT,    NFMAX =  28
NOMINAL DESIGN PARAMETER,        JNOM =  28
X-LOCATION INPUT PARAMETER,    INXLOC =   0
F-LOCATION INPUT PARAMETER,    INFLOC =   0
TAYLER SERIES I.D. CODE,       MAXTRM =   2
```

```
DELTA-X BOUNDS FOR APPROXIMATE OPTIMIZATION
0.2000E+01  0.2000E+01  0.2000E+01  0.2000E+01

MULTIPLIER ON DELX,           XFACT1 =  0.1500E+01
MULTIPLIER ON DELX,           XFACT2 =  0.2000E+01

GLOBAL LOCATIONS OF X-VARIABLES
    1    2    3    4

GLOBAL LOCATIONS OF FUNCTIONS
    9    6    7

X-VECTORS INPUT FROM UNIT    5

NUMBER    1     DESIGN    1
0.2900E+02  0.1800E+02  0.1500E+02  0.1100E+02

NUMBER    2     DESIGN    2
```

```
0.2700E+02  0.1800E+02  0.1500E+02  0.1100E+02

NUMBER   3    DESIGN   3
0.2700E+02  0.1600E+02  0.1500E+02  0.1100E+02

NUMBER   4    DESIGN   4
0.2700E+02  0.1600E+02  0.1300E+02  0.1100E+02

NUMBER   5    DESIGN   5
0.2700E+02  0.1600E+02  0.1300E+02  0.9000E+01

* * ESTIMATED DATA STORAGE REQUIREMENTS

           REAL                              INTEGER
INPUT  EXECUTION  AVAILABLE       INPUT  EXECUTION  AVAILABLE
  41      335       5000            30       78        1000
********************************

SET VANE 1 TO   29.00 DEGREES

SET VANE 2 TO   18.00 DEGREES

SET VANE 3 TO   15.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD OL   CONSTANT AT A VALUE OF         76.779
PRESSURE RATIO=  5.5330

SURGE MARGIN=    8.3000

EFFICIENCY=     87.1400

********************************

********************************

SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   18.00 DEGREES

SET VANE 3 TO   15.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD OL   CONSTANT AT A VALUE OF         76.779
PRESSURE RATIO=  5.5970

SURGE MARGIN=    8.7400
```

```
EFFICIENCY=     87.3200

********************************

********************************

SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   16.00 DEGREES

SET VANE 3 TO   15.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RFMC CONSTANT AT A VALUE OF      5567.500
HOLD OL   CONSTANT AT A VALUE OF        76.779
PRESSURE RATIO=  5.6290

SURGE MARGIN=    8.8700

EFFICIENCY=     87.2400

********************************

********************************

SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   16.00 DEGREES

SET VANE 3 TO   13.00 DEGREES

SET VANE 4 TO   11.00 DEGREES

HOLD RFMC CONSTANT AT A VALUE OF      5567.500
HOLD OL   CONSTANT AT A VALUE OF        76.779
PRESSURE RATIO=  5.6500

SURGE MARGIN=    9.1400

EFFICIENCY=     87.2700

********************************

********************************

SET VANE 1 TO   27.00 DEGREES

SET VANE 2 TO   16.00 DEGREES

SET VANE 3 TO   13.00 DEGREES

SET VANE 4 TO    9.00 DEGREES

HOLD RFMC CONSTANT AT A VALUE OF      5567.500
HOLD OL   CONSTANT AT A VALUE OF        76.779
PRESSURE RATIO=  5.6830

SURGE MARGIN=    9.2000

EFFICIENCY=     87.3200

********************************
```

```
APPROXIMATE OPTIMIZATION ITERATION HISTORY

APPROXIMATING FUNCTION    1 IS THE OBJECTIVE

APPROXIMATING FUNCTIONS ASSOCIATED WITH CONSTRAINTS
    2    3

DESIGN VARIABLE NUMBERS ASSOCIATED WITH APPROXIMATING VARIABLES
    1    2    3    4


BEGIN ITERATION NUMBER    1

NOMINAL DESIGN NUMBER =    5

X-VECTOR
  0.27000E+02  0.16000E+02  0.13000E+02  0.90000E+01

FUNCTION VALUES
  0.56030E+01  0.92000E+01  0.87320E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.20000E+01 -0.20000E+01 -0.20000E+01 -0.20000E+01

X-VECTOR
  0.25000E+02  0.14000E+02  0.11000E+02  0.70000E+01

APPROXIMATE FUNCTION VALUES
  0.58330E+01  0.10100E+02  0.87500E+02
*********************************

SET VANE 1 TO   25.00 DEGREES

SET VANE 2 TO   14.00 DEGREES

SET VANE 3 TO   11.00 DEGREES

SET VANE 4 TO    7.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD CL   CONSTANT AT A VALUE OF        76.779
PRESSURE RATIO=  5.8390

SURGE MARGIN=    9.6400

EFFICIENCY=     87.4000

*********************************


PRECISE FUNCTION VALUES
  0.58390E+01  0.96400E+01  0.87400E+02
```

```
BEGIN ITERATION NUMBER     2

NOMINAL DESIGN NUMBER =     6

X-VECTOR
  0.25000E+02  0.14000E+02  0.11000E+02  0.70000E+01

FUNCTION VALUES
  0.58390E+01  0.96400E+01  0.87400E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.30000E+01  0.80461E+00 -0.20000E+01 -0.20000E+01

X-VECTOR
  0.22000E+02  0.14805E+02  0.90000E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.59764E+01  0.90252E+01  0.87445E+02
********************************

SET VANE 1 TO   22.00 DEGREES

SET VANE 2 TO   14.80 DEGREES

SET VANE 3 TO    9.00 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF       5567.500
HOLD OL   CONSTANT AT A VALUE OF         76.779
PRESSURE RATIO=  5.9580

SURGE MARGIN=   10.0200

EFFICIENCY=     87.3100

********************************

PRECISE FUNCTION VALUES
  0.59580E+01  0.10020E+02  0.87310E+02

BEGIN ITERATION NUMBER     3

NOMINAL DESIGN NUMBER =     7

X-VECTOR
  0.22000E+02  0.14805E+02  0.90000E+01  0.50000E+01

FUNCTION VALUES
  0.59580E+01  0.10020E+02  0.87310E+02
```

RESULTS OF APPROXIMATE OPTIMIZATION

OPTIMIZATION HAS PRODUCED AN X-VECTOR WHICH IS THE SAME AS A PREVIOUS DESIGN

DELTA-X VECTOR
0.36198E-06 -0.73096E-06 -0.92256E-06 -0.97167E-06

X-VECTOR
0.22000E+02 0.14805E+02 0.90000E+01 0.50000E+01

THE FOLLOWING DESIGN IS NOT THE APPROXIMATE OPTIMUM

DELTA-X VECTOR
0.60000E-01 0.59999E-01 0.39999E-01 0.19999E-01

X-VECTOR
0.22060E+02 0.14865E+02 0.90400E+01 0.50200E+01

APPROXIMATE FUNCTION VALUES
0.59543E+01 0.10024E+02 0.87317E+02
****

SET VANE 1 TO 22.06 DEGREES

SET VANE 2 TO 14.86 DEGREES

SET VANE 3 TO 9.04 DEGREES

SET VANE 4 TO 5.02 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF 5567.500
HOLD OL CONSTANT AT A VALUE OF 75.779
PRESSURE RATIO= 5.9550

SURGE MARGIN= 9.9900

EFFICIENCY= 87.3200

****

PRECISE FUNCTION VALUES
0.59550E+01 0.99900E+01 0.87320E+02

BEGIN ITERATION NUMBER 4

NOMINAL DESIGN NUMBER = 8

X-VECTOR
0.22060E+02 0.14865E+02 0.90400E+01 0.50200E+01

FUNCTION VALUES
0.59550E+01 0.99900E+01 0.87320E+02

```
RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.69780E+00 -0.99378E+00 -0.46939E+00 -0.20000E-01

X-VECTOR
  0.22758E+02  0.13871E+02  0.85706E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.59993E+01  0.85006E+01  0.87510E+02
********************************

SET VANE 1 TO   22.76 DEGREES

SET VANE 2 TO   13.87 DEGREES

SET VANE 3 TO    8.57 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF     5567.500
HOLD OL    CONSTANT AT A VALUE OF       76.779
PRESSURE RATIO=  5.9630

SURGE MARGIN=    9.9900

EFFICIENCY=     87.3200

********************************


PRECISE FUNCTION VALUES
  0.59630E+01  0.99900E+01  0.87320E+02


BEGIN ITERATION NUMBER     5

NOMINAL DESIGN NUMBER =     9

X-VECTOR
  0.22758E+02  0.13871E+02  0.85706E+01  0.50000E+01

FUNCTION VALUES
  0.59630E+01  0.99900E+01  0.87320E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.26699E+01 -0.30000E+01  0.19486E+01  0.0

X-VECTOR
  0.20000E+02  0.10871E+02  0.10519E+02  0.50000E+01

APPROXIMATE FUNCTION VALUES
```

```
    0.60790E+01  0.10146E+02  0.8712[illegible]E+02
**********************************

    SET VANE 1 TO   20.09 DEGREES

    SET VANE 2 TO   10.87 DEGREES

    SET VANE 3 TO   10.52 DEGREES

    SET VANE 4 TO    5.00 DEGREES

    HOLD RPMC CONSTANT AT A VALUE OF      5567.500
    HOLD OL   CONSTANT AT A VALUE OF        76.779
    PRESSURE RATIO=  6.0360

    SURGE MARGIN=   10.0800

    EFFICIENCY=     86.9100

**********************************


    PRECISE FUNCTION VALUES
      0.60360E+01  0.10080E+02  0.86910E+02


    BEGIN ITERATION NUMBER    6

    NOMINAL DESIGN NUMBER =   10

    X-VECTOR
      0.20093E+02  0.10871E+02  0.10519E+02  0.50000E+01

    FUNCTION VALUES
      0.60360E+01  0.10080E+02  0.86910E+02


    RESULTS OF APPROXIMATE OPTIMIZATION

    DELTA-X VECTOR
      0.15720E+01 -0.30000E+01  0.10868E+01  0.0

    X-VECTOR
      0.21660E+02  0.78708E+01  0.11606E+02  0.50000E+01

    APPROXIMATE FUNCTION VALUES
      0.61003E+01  0.86785E+01  0.87345E+02
**********************************

    SET VANE 1 TO   21.66 DEGREES

    SET VANE 2 TO    7.87 DEGREES

    SET VANE 3 TO   11.61 DEGREES

    SET VANE 4 TO    5.00 DEGREES
```

```
HOLD RPMC CONSTANT AT A VALUE OF        5567.500
HOLD OL   CONSTANT AT A VALUE OF          76.779
PRESSURE RATIO=  6.0270

SURGE MARGIN=    9.9100

EFFICIENCY=     86.8300

********************************

PRECISE FUNCTION VALUES
  0.60270E+01  0.99100E+01  0.86830E+02

BEGIN ITERATION NUMBER     7

NOMINAL DESIGN NUMBER =    11

X-VECTOR
  0.21660E+02  0.78708E+01  0.11606E+02  0.50000E+01

FUNCTION VALUES
  0.60270E+01  0.99100E+01  0.86830E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.41267E-01  0.73487E-01 -0.30000E+01 -0.35763E-06

X-VECTOR
  0.21701E+02  0.79443E+01  0.86060E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.60017E+01  0.10023E+02  0.86931E+02
********************************

SET VANE 1 TO   21.70 DEGREES

SET VANE 2 TO    7.94 DEGREES

SET VANE 3 TO    8.61 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF        5567.500
HOLD OL   CONSTANT AT A VALUE OF          76.779
PRESSURE RATIO=  6.0690

SURGE MARGIN=   10.1900

EFFICIENCY=     86.8000

********************************
```

```
PRECISE FUNCTION VALUES
  0.60690E+01  0.10190E+02  0.86880E+02


BEGIN ITERATION NUMBER    8

NOMINAL DESIGN NUMBER =   12

X-VECTOR
  0.21701E+02  0.79443E+01  0.86060E+01  0.50000E+01

FUNCTION VALUES
  0.60690E+01  0.10190E+02  0.86880E+02


* * CONMIN DETECTS INITIAL X(I).LT.VLB(I)
X(I) =  0.0          VLB(I) =  0.9537E-06
X(I) IS SET EQUAL TO VLB(I) FOR I =    4


RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
 -0.11016E+01  0.24208E+01 -0.30000E+01  0.21580E-05

X-VECTOR
  0.20600E+02  0.10365E+02  0.56060E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.61052E+01  0.10423E+02  0.86997E+02
*********************************


SET VANE 1 TO   20.60 DEGREES

SET VANE 2 TO   10.37 DEGREES

SET VANE 3 TO    5.61 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD OL   CONSTANT AT A VALUE OF        76.779
PRESSURE RATIO=  6.1030

SURGE MARGIN=   10.1800

EFFICIENCY=     86.8200
*********************************


PRECISE FUNCTION VALUES
  0.61030E+01  0.10180E+02  0.86820E+02
```

```
BEGIN ITERATION NUMBER    9

NOMINAL DESIGN NUMBER =   13

X-VECTOR
  0.20600E+02  0.10365E+02  0.56060E+01  0.50000E+01

FUNCTION VALUES
  0.61030E+01  0.10180E+02  0.86820E+02

RESULTS OF APPROXIMATE OPTIMIZATION

DELTA-X VECTOR
  0.44074E+00 -0.21178E+00 -0.60598E+00  0.0

X-VECTOR
  0.21040E+02  0.10153E+02  0.50000E+01  0.50000E+01

APPROXIMATE FUNCTION VALUES
  0.61053E+01  0.10138E+02  0.86828E+02
********************************

SET VANE 1 TO   21.04 DEGREES

SET VANE 2 TO   10.15 DEGREES

SET VANE 3 TO    5.00 DEGREES

SET VANE 4 TO    5.00 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF      5567.500
HOLD OL   CONSTANT AT A VALUE OF        76.779
PRESSURE RATIO=  6.1020

SURGE MARGIN=   10.2100

EFFICIENCY=     86.8000

********************************

PRECISE FUNCTION VALUES
  0.61020E+01  0.10210E+02  0.86800E+02

BEGIN ITERATION NUMBER   10

NOMINAL DESIGN NUMBER =   14

X-VECTOR
  0.21040E+02  0.10153E+02  0.50000E+01  0.50000E+01

FUNCTION VALUES
  0.61020E+01  0.10210E+02  0.86800E+02
```

RESULTS OF APPROXIMATE OPTIMIZATION

OPTIMIZATION HAS PRODUCED AN X-VECTOR WHICH IS THE SAME AS A PREVIOUS DESIGN

DELTA-X VECTOR
-0.53784E-07 0.0 0.0 0.0

X-VECTOR
0.21040E+02 0.10153E+02 0.50000E+01 0.50000E+01

THE FOLLOWING DESIGN IS NOT THE APPROXIMATE OPTIMUM

DELTA-X VECTOR
0.20000E-01 0.20000E-01 0.10000E-01 0.10000E-01

X-VECTOR
0.21060E+02 0.10173E+02 0.50100E+01 0.50100E+01

APPROXIMATE FUNCTION VALUES
0.61010E+01 0.10210E+02 0.86804E+02
****

SET VANE 1 TO 21.06 DEGREES

SET VANE 2 TO 10.17 DEGREES

SET VANE 3 TO 5.01 DEGREES

SET VANE 4 TO 5.01 DEGREES

HOLD RPMC CONSTANT AT A VALUE OF 5567.500
HOLD OL CONSTANT AT A VALUE OF 76.779
PRESSURE RATIO= 6.1050

SURGE MARGIN= 10.1500

EFFICIENCY= 86.8200

****

PRECISE FUNCTION VALUES
0.61050E+01 0.10150E+02 0.86820E+02

FINAL RESULT OF APPROXIMATE OPTIMIZATION

NOMINAL DESIGN NUMBER = 15

X-VECTOR
0.21060E+02 0.10173E+02 0.50100E+01 0.50100E+01

FUNCTION VALUES
0.61050E+01 0.10150E+02 0.86820E+02

RESULTS OF APPROXIMATE ANALYSIS/OPTIMIZATION

TITLE
****

```
GLOBAL LOCATIONS OF X-VARIABLES
     1     2     3     4

GLOBAL LOCATIONS OF FUNCTIONS, F(X)
     9     6     7

APPROXIMATION IS BASED ON   15 DESIGNS

NOMINAL DESIGN IS DESIGN NUMBER   15

VALUES OF X-VARIABLES
    0.2106E+02   0.1017E+02   0.5010E+01   0.5010E+01

VALUES OF FUNCTIONS, F(X)
    0.6105E+01   0.1015E+02   0.8682E+02

COEFFICIENTS OF TAYLOR SERIES EXPANSION

PARAMETER    1 = GLOBAL VARIABLE    9

LINEAR TERMS, DEL F
   -0.2044E-01  -0.1362E-01  -0.1451E-01  -0.1750E-01

NON-LINEAR TERMS, H, BEGINING WITH DIAGONAL ELEMENT

ROW    1
   -0.1648E-02

ROW    2
   -0.5373E-03

ROW    3
    0.3395E-04

ROW    4
    0.6565E-03

PARAMETER    2 = GLOBAL VARIABLE    6

LINEAR TERMS, DEL F
   -0.4634E-01  -0.1312E-01   0.4856E-01   0.7715E-01

NON-LINEAR TERMS, H, BEGINING WITH DIAGONAL ELEMENT

ROW    1
   -0.2460E-01

ROW    2
   -0.3261E-02

ROW    3
   -0.2394E-01

ROW    4
   -0.1294E-01
```

```
PARAMETER    3 = GLOBAL VARIABLE    7

LINEAR TERMS, DEL F
   0.1044E+00   0.6735E-01   0.5474E-01  -0.4966E-02

NON-LINEAR TERMS, H, BEGINING WITH DIAGONAL ELEMENT

ROW    1
  -0.2775E-01

ROW    2
  -0.3713E-02

ROW    3
  -0.9915E-02

ROW    4
  -0.4343E-02

 OPTIMIZATION RESULTS

 OBJECTIVE FUNCTION
 GLOBAL LOCATION      9      FUNCTION VALUE 0.61050E+01

 DESIGN VARIABLES

           D. V.    GLOBAL       LOWER                      UPPER
     ID     NO.    VAR. NO.      BOUND        VALUE         BOUND
      1      1         1     0.10000E+02  0.21060E+02  0.35000E+02
      2      2         2     0.50000E+01  0.10173E+02  0.25000E+02
      3      3         3     0.50000E+01  0.50100E+01  0.25000E+02
      4      4         4     0.50000E+01  0.50100E+01  0.25000E+02

 DESIGN CONSTRAINTS

           GLOBAL      LOWER                      UPPER
     ID   VAR. NO.     BOUND        VALUE         BOUND
      1       6     0.85000E+01  0.10150E+02  0.10000E+03
      3       7     0.87000E+02  0.86820E+02  0.10000E+04

 **** *** FINAL SOLUTION VALUES ********

 VANE ANGLE FOR VANE 1 IS        21.06 DEGREES

 VANE ANGLE FOR VANE 2 IS        10.17 DEGREES

 VANE ANGLE FOR VANE 3 IS         5.01 DEGREES

 VANE ANGLE FOR VANE 4 IS         5.01 DEGREES

 PRESSURE RATIO=  6.1050

 EFFICIENCY=     86.8200

 SURGE MARGIN=   10.1500

 RPMC WAS HELD CONSTANT AT       5567.50
 OL   WAS HELD CONSTANT AT         76.78

 PROGRAM CALLS TO ANALIZ

    ICALC   CALLS
      1       1
      2      15
      3       1
```

DATE
FILMED
0-8